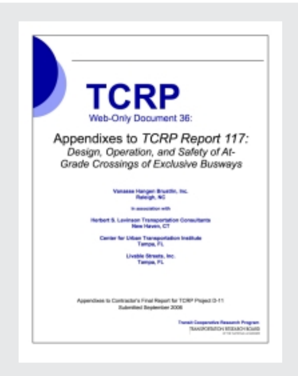


Appendixes to TCRP Report 117: Design, Operation, and Safety of At-Grade Crossings of Exclusive Busways

DETAILS

0 pages | null | PAPERBACK
ISBN 978-0-309-43641-0 | DOI 10.17226/23180

AUTHORS

ACKNOWLEDGMENT

This work was sponsored by the Federal Transit Administration (FTA) in cooperation with the Transit Development Corporation. It was conducted through the Transit Cooperative Research Program (TCRP), which is administered by the Transportation Research Board (TRB) of the National Academies.

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. On the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. William A. Wulf is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, on its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both the Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. William A. Wulf are chair and vice chair, respectively, of the National Research Council.

The **Transportation Research Board** is a division of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's mission is to promote innovation and progress in transportation through research. In an objective and interdisciplinary setting, the Board facilitates the sharing of information on transportation practice and policy by researchers and practitioners; stimulates research and offers research management services that promote technical excellence; provides expert advice on transportation policy and programs; and disseminates research results broadly and encourages their implementation. The Board's varied activities annually engage more than 5,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation. **www.TRB.org**

www.national-academies.org

Author Acknowledgments

The research reported herein was performed under TCRP Project D-11 by Vanasse Hangen Brustlin, Inc. (VHB); Center for Urban Transportation Research at the University of South Florida; Livable Streets, Inc.; and Herbert Levinson. VHB was the prime contractor for this study. Work undertaken by the University of South Florida, Livable Streets, and Mr. Levinson was under subcontract with VHB. Kim Eccles, P.E., of VHB was the principal investigator and is one of the authors of this report. The other author of this report is Herbert Levinson. Cheryl Thole and Joel Volinski of the Center for Urban Transportation Research at the University of South Florida are the authors of Appendix A. Significant contributions to the report were made by Nancy Xenelis, Frank Spielberg, Joedel Zaballero, Charlie O'Connell, and Dibyendu Sengupta, all of VHB; Michael Moule of Livable Streets, Inc.; and Alasdair Cain, Dennis Hinebaugh, Cheryl Thole, and Joel Volinski, all of the University of South Florida.

The authors would like to acknowledge the contributions of the following individuals around the United States and Canada who provided information for this effort:

- William Hoople, Service Planner/Scheduler, Regional Transportation District, Denver, Colorado
- Ralph Stavermann, Traffic Engineer, City of Denver, Colorado
- Mike Zamiska, Director-System Safety, Port Authority of Allegheny County, Pennsylvania
- Sean Skehan, Senior Transportation Engineer, City of Los Angeles Department of Transportation, California
- Gary Spivak, Division Transportation Manager, and staff, Los Angeles County Metropolitan Transportation Authority, California
- Rex Gephart, Bus Rapid Transit Manager, Los Angeles County Metropolitan Transportation Authority, California
- Rory Santana, District VI Traffic Operations Engineer, Florida Department of Transportation, Florida
- Bob Williams, Traffic Control Center Engineer, Miami-Dade County Department of Public Works, Florida
- David Fialkoff, Director of Service Planning and Scheduling, Miami-Dade Transit, Florida
- Mike Schipper, General Manager-Development, Greater Cleveland Regional Transportation Authority, Cleveland, Ohio
- Jomarie Wasik, Assistant Director, Department of Public Service, City of Cleveland, Ohio
- John Motl, Modes Manager Engineer, Ohio Department of Transportation District 12
- Terry Dolan, Manager of Rail Transportation, Tri-Met, Portland, Oregon
- Brian Mills, Transit Planning Manager, TransLink (Greater Vancouver Transportation Authority), Vancouver, British Columbia, Canada

- Hansel Wang, Program Manager, Transportation Engineering, Road and Infrastructure Planning, TransLink (Greater Vancouver Transportation Authority), Vancouver, British Columbia, Canada
- Colin Leech, Transit Planner, OC Transpo, Ottawa, Ontario, Canada
- Kornel Mucsi, Transit Priority Projects Manager, City of Ottawa, Ontario, Canada
- Doug Jamison, Project Manager, LYNX Planning, Orlando, Florida
- Charles Ramdatt, City Transportation Engineer, City of Orlando, Florida
- John Rhoades, Project Manager, City of Orlando, Florida
- Michael Sanders, Transit and Rideshare Administrator, Connecticut Department of Transportation
- Mark Rolfe, Project Manager, Connecticut Department of Transportation
- Jim Cunradi, Project Manager, Alameda-Contra Costa Transit District (AC Transit), Oakland, California
- Jamie Levin, Director of Marketing & Communications, Alameda-Contra Costa Transit District (AC Transit), Oakland, California
- Graham Carey, BRT Project Engineer, Lane Transit District, Eugene, Oregon
- Gary McNeel, Senior Transportation Analyst, Public Works Engineering, City of Eugene, Oregon
- Maria Reynolds, Division Transportation Manager, West San Fernando Valley Division, Metropolitan Transportation Authority, Los Angeles, California
- George Trudeau, Assistant Transportation Manager, Metro San Fernando Valley, Metropolitan Transportation Authority, Los Angeles, California
- Michael C. Hunt, P.E., Transportation Engineering Associate III, Department of Transportation, City of Los Angeles, California
- John Fisher, P.E., P.T.O.E., Assistant General Manager, Office of Transportation Operations, Department of Transportation, City of Los Angeles, California
- Kathleen Sanchez, Transportation Planning Manager, Metropolitan Transportation Authority, Los Angeles, California
- Morteza Delpasand, P.E., Transportation Engineer, Department of Transportation, City of Los Angeles, California
- Robert H. Torres, Corporate Safety Manager, Corporate Safety, Metropolitan Transportation Authority, Los Angeles, California
- R. Scott Page, Transportation Planning Manager IV, Regional Transit Planning, Metropolitan Transportation Authority, Los Angeles, California
- Hitesh Patel, P.E., Director, Construction Project Management, Metropolitan Transportation Authority, Los Angeles, California
- Vijay Khawani, Director, Corporate Safety and Rail Operations, Metropolitan Transportation Authority, Los Angeles, California
- Representatives from Miami-Dade Transit including Isabel Padron, Albert Hernandez, Eric Muntan, and Derrick Gordon

TCRP Web-Only Document 36: Appendixes to TCRP Report 117

CONTENTS

APPENDIX A
LITERATURE REVIEW

INTRODUCTION

One of the objectives of transit agencies is to ensure the safety of not only transit patrons, but of motorists and pedestrians that may be affected by their system's operations. With the objective to keep incidents to a minimum, a number of measures are taken within the transit industry. Considerations must be based on the characteristics of the system's environment and operating conditions. Systems running on their own right-of-way (ROW) but also sharing the ROW (grade crossings) at times must be given their own safety considerations.

Busways, a relatively new addition to the transit industry in the U.S., have many of the same characteristics at at-grade crossings as light rail systems. However, because few systems are in place, detailed information on the best way to safely accommodate busways at crossings is limited. Safety considerations for busways, therefore, may also look to industry experience with grade crossings at light rail systems. Literature on traffic signing and signals, busway characteristics, and industry experiences has been reviewed as part of this research to provide an understanding of safety issues and traffic enhancements at-grade crossings and is presented in the following literature review.

Dedicated busways on exclusive rights-of-way are the most attractive options for bus rapid transit (BRT) systems, although busways are not limited to BRT systems. The physical separation of buses from other traffic is a true rapid transit option. Faster travel times, and more reliable bus operations are achieved. In addition, speeds that are similar to those offered by rapid transit are provided. The costs of busway transit, however, are relatively less than that of rail transit. According to *TCRP Report 90 (1)*, busways provide 1) line-haul BRT services to city centers; 2) BRT service that extend rail transit lines; and 3) short bypasses of major congestion points. Busways can be constructed on separate rights-of-way, alongside arterials, or within arterial medians. Busways may also be designed as "open" systems (buses enter or leave at intermediate points) or "closed" systems (buses operate only on the busway). In addition, busways may be fully or partially separated, or may provide service entirely at-grade.

The objective of at-grade busways is to attract automobile users from major traffic corridors to replace their trips with transit trips by improving comfort, reliability, travel time, economy, and quality of transit services. The *At-grade Busway Planning Guide (2)* identified five advantages that busway transit systems offer:

1) Flexibility – Aside from providing a large number of one seat trips, busways can match capacity demands and service quality. Busway transit routes can serve a larger passenger catchment area, decreasing the need for passenger transfers.

2) Low construction costs – Busways can be constructed by using existing or abandoned right-of-way, or a street median thereby requiring relatively little capital output. The maintenance and operating costs associated with busways can be less than those with rail technology.

3) Self enforcement – Vehicles operating on their own right-of-way are virtually self-enforcing.

4) Implementation speed – A busway may be implemented relatively quickly since legislation is seldom necessary and the vehicles and running way do not have to be modified as they would for rail.

5) Incremental development – Busway transit can be implemented and enhanced through stages.

Although these five advantages were identified in the *At-grade Busway Planning Guide (2),* the advantages of implementation speed are debatable. Implementation speed may be slow if a separate ROW is constructed. Additionally, describing busways as "self enforcing" may be an incorrect assessment. More appropriately, when transit vehicles operate in an exclusive ROW, identifying vehicles that are in violation is far easier than when bus priority is provided on a roadway that also serves mixed traffic.

SAFETY OF AT-GRADE CROSSINGS

Like light rail transit (LRT), at-grade busways can provide a safe mode of transportation in terms of total crashes per mile. When crashes occur, they affect the public image of transit and increase the liability of agencies. It is necessary to provide for an appropriate planning, design, and operation process during which an effort is made to minimize the potential for these conflicts. Competent choices for alignment are necessary for safe busway operations. The alignment must be chosen after considering characteristics of the travel patterns (pedestrian and general traffic) and roadway operating conditions. Because of the similarity with at-grade automobile, bicycle, and/or pedestrian crossings between LRT and busways, some of the same safety considerations for LRT can be applied to busway systems.

Types of Busways and Potential Problems

The inclusion of a new busway into an existing roadway is a difficult task, as the road is already shared with different users with different demands. A median at-grade busway would likely be constructed where two lanes are provided for buses traveling in different directions. If sufficient right-of-way exists near intersections, two extra lanes (one in each direction) can be added.

A side-aligned busway is generally constructed along newly constructed corridors where the right-of-way is reserved. A side-aligned busway consists of an exclusive two-lane roadway where each lane is reserved for one direction for buses to travel. If there is sufficient right-of-way, an extra four feet of separation between the two directions should be added *(2)*.

A third type of busway intersection is at separated right-of-way busway alignments. This intersection is not located near any parallel roadway.

An overview of accident types, and suggested actions to mitigate problems, as reported in *TCRP Report 17(3)* (for LRT) and the *At-grade Busway Planning Guide (2)* for two types of busways, side-aligned and median at-grade busways is provided in the following sections.

Side-Aligned At-Grade Busway

1) "Pedestrians trespass on side-aligned at-grade busway right-of-ways where no sidewalk is provided. *Solution: Install fence or install sidewalk if none exists.*

2) Pedestrians jaywalk across at-grade busway right-of-ways due to the absence of sidewalks on both sides of the side-aligned at-grade busways. *Solution: Install fence to separate the busway right-of-way or provide curbside landscaping, bollards, or barriers*.
3) Pedestrian and motorist confusion about which way the busway vehicle is approaching. Solution: Busway vehicle should operate with headlight on all the time and install internally illuminated signs displaying the front or side view of a bus and the direction of approach.
4) Side-aligned two-way at-grade busways operating on a two-way street may cause confusion to motorists, especially at night when the headlight of an approaching busway vehicle appears on the right-hand side of the road. *Solution: Replace side running with median options.*
5) Motorists make illegal left turns across the busway immediately after the termination of their left turn green arrow. As a result, they might be unaware of a busway vehicle approaching the intersection at a higher speed. *Solution: Improve enforcement and install active BUS COMING signs.*
6) Motorists violate the right-turn red arrow and may be unaware of a busway vehicle approaching the intersection from the left-hand side. *Solution: Improve enforcement and install active BUS COMING signs.*
7) Red time extension due to multiple busway vehicle preemption may make motorists who are waiting to cross the busway tracks to become impatient. *Solution: Limit multiple bus preemption within the same cycle*.
8) Complex intersection geometry may cause confusion to motorists, pedestrians and bicyclists and complicate their decision-making about crossing busway intersections. *Solution: Simplify roadway geometry and use traffic signals or other active controls to restrict motor vehicle movements while a busway vehicle crosses the intersection."*

Median At-Grade Busways

1) "Lack of safe, clearly defined pedestrian crossings at stations, intersections and mid-block locations may be a source of hazards to pedestrians. *Solution: Define pedestrian pathways; design stations to prevent random crossings of the busway lanes, install safety islands; and install pedestrian automatic gates, swing gates, bedstead barriers, or z-crossings.*
2) Lack of passenger waiting areas. Solution: Provide a sufficient passenger waiting area to handle the maximum expected number of passengers at peak periods.
3) Motorists violating traffic signals at perpendicular at-grade crossings try to beat busway vehicles to the intersection, especially when the busway vehicles are moving at relatively low speed. *Solution: Improve enforcement, provide a left-turn phase after a through busway vehicle phase, and/or install active BUS COMING signs.*
4) Motorists making left-turns blocking the busway right-of-way. Solution: Coordinate traffic signal phasing and timing at intersections and provide sufficient left-turn storage pockets.

5) Motorist confusion between the busway signals and general traffic signals especially left-turn signals. Solution: Provide busway signals that are clearly distinguishable from traffic signals and whose indications are meaningless to motorists and pedestrians."

Please note that these are the recommendations reported in the two referenced documents but do not necessarily reflect the opinions of the TCRP D-11 project team.

Physical Characteristics of Roadway Affecting Safety

Awareness of Crossings

Motorists, pedestrians, and bicyclists crossing busways must be aware of the presence of the crossing. This may be a particular problem if buses do not cross the intersection on a frequent interval, if there is a downstream intersection in close proximity, or if there is visual clutter from the intersection. Various traffic control devices can be used to alert motorists, pedestrians, and bicycles to the presence of the intersection. Light rail systems have experienced similar issues. *TCRP Report 69* surveyed LRT systems and identified awareness of the crossing and disregard of grade crossing warning devices as a safety problem *(4)*. Visual clutter was attributed as one of the causes.

Sight Distance

The physical characteristics of at-grade crossings also affect a driver's or pedestrian's ability to see an approaching vehicle. Sight distance, the set of distances along the highway and along the busway needed by a user to detect the presence of a vehicle in time to stop, is a characteristic that may affect their ability to respond to an oncoming vehicle. Guidelines provided by the American Association of State Highway and Transportation Officials (AASHTO) determine that at-grade crossings should be designed so an approaching motorist is able to see the vehicle, react, and stop prior to the crossing *(5)*.

Angle

The angle at which the roadway meets the busway also affects the ability for a driver or pedestrian to see an oncoming vehicle. When an angle is skewed it takes a vehicle longer to safely clear the intersection. According to AASHTO, "for safety and economy, intersecting roads should generally meet at or nearly at right angles." AASHTO also recommends that when an acute angle of intersection exists, the road be realigned so that the angle of the intersection can be closer to 90 degrees *(5)*.

Curvature

Roadway or busway curvature can also affect a driver's ability to see an oncoming vehicle. When a driver's trajectory includes a curve, their ability to determine the speed and distance of another vehicle is more difficult than without a curve. In addition, the driver may be preoccupied by the effort to maneuver along the curve. AASHTO recommends that crossing should not be located on curves whenever it is possible *(5)*.

Left and Right Turn Treatments

Left and right turns across busways may affect the safety of the crossing by increasing the number of potential conflicts between buses, motorists, and non-motorized users. Turn restrictions may be put in place to reduce those conflicts.

Safety at Light Rail Intersections

TCRP Report 17 explored the safety of light rail crossings of roadway in city streets *(3)*. Table A-1 presents an overview of the common problems experienced by the ten LRT systems surveyed for the report and provides suggestions for possible solutions. Although the systems varied in operations, alignments, and design, there were common safety problems experienced by all of them. Many of these problems are not unique to LRT, and are directly applicable to busways. For example, the problem reported most frequently by survey respondents is motorists turning left in front of overtaking LRVs.

Table A-1: Possible Solutions to Observed Problems
(Source: *TCRP Report 17: Integration of Light Rail Transit into City Streets)*

PROBLEM	POSSIBLE SOLUTION
1 PEDESTRIAN SAFETY	
• Trespass on tracks	Install fence Install sidewalk if none exists
• Jaywalk	Install fence/barrier between tracks, or to separate LRT r-o-w Provide curbside landscaping, bollards, barriers
• Station and/or cross-street access	Define pedestrian pathways Provide adequate storage/queuing space Design station to preclude random crossings of tracks Install safety islands. Install pedestrian automatic gates, swing gates, bedstead barriers, and Z-crossings
2 SIDE-RUNNING ALIGNMENT	Operate LRVs with headlights on and use audible devices Close driveways especially through land use changes Prohibit conflicting left or right turns by parallel traffic Provide separate turning lanes and phases for conflicting traffic Provide LRV-only signal phase. Provide a comfort zone between dynamic envelope and curb Replace side-running with median operations
3 VEHICLES OPERATING PARALLEL TO LRT R-O-W TURNING LEFT ACROSS TRACKS	
• Illegal left turns	Provide left turn phase after through/LRV phase Limit multiple LRV preemptions within same cycle Install active TRAIN APPROACHING signs
• Protected left turn lanes with signal phases	Install active TRAIN APPROACHING signs Improve enforcement (e g , photo enforcement)
4 TRAFFIC CONTROL OBSERVANCE	
• Passive turn restriction sign violations	Install active signs.
• Active turn restriction sign violations	Improve enforcement
• Confusing traffic signal displays	Provide distinctive LRT signals that are placed at separate locations Louver or optically program out conflicting signal indications
• Poor delineation of dynamic envelope	Delineate dynamic envelope by contrasting pavement color and/or texture or paint
5. MOTOR VEHICLES ON TRACKS	Install NO VEHICLES ON TRACKS signs Pave tracks with different texture/paint Pave tracks at slightly different elevation (e g , 4" above tracks)
6 CROSSING SAFETY (RIGHT-ANGLE ACCIDENTS)	Increase all-red clearance intervals for cross-street traffic Modify or limit LRV preemption to maintain cross-street progression Provide photo enforcement
7 POOR INTERSECTION GEOMETRY	Simplify roadway lane geometries Use traffic signals or other active controls to restrict motor vehicle movements while LRVs cross

INDUSTRY STANDARDS AND GUIDELINES

A good program of traffic controls and signage should help ensure safe vehicle and pedestrian crossings of bus lanes and busways and minimize delays to buses vehicles and general traffic. Good traffic controls and signage will maintain essential access to curbside activities and provide a reasonable allocation of street space among competing uses—BRT, other buses, and curbside access for general traffic and pedestrians. A number of standards and guidelines have been suggested by various agencies and reports for achieving a successful and safe system.

Design Guidelines

The American Association of State Highway and Transportation Officials (AASHTO) provides design guidance in the publication *A Policy on Geometric Design of Highways and Streets (5).* This is commonly referred to in the traffic engineering parlance as the AASHTO Green Book. The Green Book contains guidelines to assist engineers in the design of safe roadway systems, including specifications for safe roadway alignment of at-grade LRT crossings, and formulas for calculating the sight distance requirements. A detailed accounting of the design guidelines related to such at-grade crossings is not included here because it is beyond the scope of this literature review.

Guidelines for the Use of Traffic Control Devices

The FHWA's Manual on Uniform Traffic Control Devices (MUTCD) *(6)* provides State and local highway engineers with standards for sign, signal, and pavement marking design, as well as for their appropriate placement. States may either adopt MUTCD standards (thereby making it state law) or adopt a State manual that conforms to the MUTCD.

Traffic control devices are the most important factors in effectively directing vehicular and non-motorized traffic. It is necessary to warn roadway users of unusual roadway (and additional) conditions to maintain a safe driving environment. A number of traffic control devices have been developed to fulfill this need, including warning signs with different symbols, pavement surface treatments, pavement markings, and flashing lights. Grade crossings are known as either being passive or active, depending on the types of traffic control devices that are being used. A passive grade crossing alerts the driver of the crossing with pavement markings and traffic signs on the roadway approach to and at the grade crossing. These markings and signs are also present at active crossings, which incorporate additional traffic control devices, such as flashing lights or vehicle activated signs, to alert a driver of an approaching vehicle, and automatic gates to prevent entry. For busways, signage and pavement markings play a large role in directing traffic that is traveling alongside and within the corridor.

Some of the relevant traffic control devices applicable to busway at-grade crossings are discussed in the following sections.

Signs

Signs are designed to attract the attention of people while they are driving, bicycling, or walking. The colors, contrasts, shapes, reflection, composition, and illumination of signs immediately convey a message that is clear to understand. The placement of signs are also key to ensuring their effectiveness, given that they must be placed at a distance from which a person has time to respond considering their traveling speed. MUTCD provides standards for the design of traffic signs. Information for the appropriate design and size of warning signs are provided in

Sections 2C-03 and 2C-04 and standards for letters in regard to size and style are provided in the *Standard Alphabets for Highway Signs.*

The MUTCD provides a specific section for light rail grade crossings. Chapter 10, Traffic Controls for Highway Light Rail Transit Grade Crossings, provides standards and guidelines for the design, operation, and integration of traffic control devices at at-grade crossings of highway traffic and light rail vehicles.

Measures that are taken at LRT crossings could also be useful for and applied to busway intersections. These may include traditional crossbuck signs, complemented by signs such as LOOK (Figure A-1), YIELD, and STOP. When used as a complement to crossbuck signs, these signs are generally used under the following conditions.

a) Crossing should be secondary in character (such as a minor street) with low traffic volumes and speed limits.

b) Light rail speeds do not exceed 25 mph (40 km/h).

c) The line of sight is sufficient whereas an operator of the transit vehicle could use an audible signal and bring the vehicle to a stop before reaching the point.

d) The driver on the road has sufficient line of sight where they can safely travel across the tracks before the light rail vehicle arrives.

e) If the intersection does not meet that guidelines as set forth in Chapter 4C.

f) The tracks are not located in a place where vehicles would likely stop while waiting to cross the intersection.

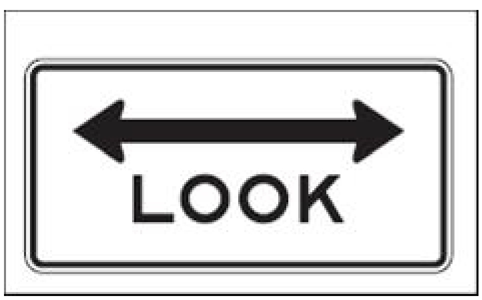


Figure A-1: MUTCD Sign R15-8 (Source: MUTCD 2003)

It is also noted that if a STOP or YIELD sign is placed after the crossing of tracks, a DO NOT STOP ON TRACKS (Figure A-2) sign should be placed at a specified location based on engineering studies (Section 10C). This sign can be placed on both sides of the track. On divided highways and streets, it can also be placed on the near or far left side of the tracks to improve visibility.

Figure A-2: MUTCD Sign R8-8 (Source: MUTCD 2003)

STOP HERE WHEN FLASHING is used to inform drivers of the point which they are to stop when flashing lights have been activated. STOP HERE ON RED draws attention to the stop required on at the intersection. It may be used where stop violations occur frequently. These signs are illustrated in Figure A-3.

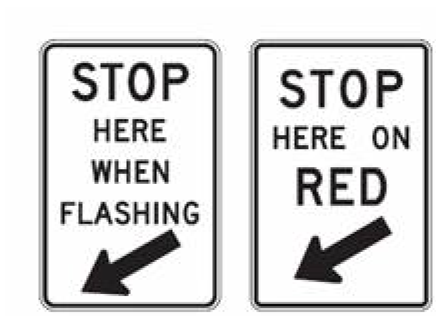


Figure A-3: MUTCD Signs R8-10 and R10-6 (Source: MUTCD 2003)

Blank-out turn prohibition signs (Figure A-4) may also be used at intersections adjacent to tracks that are controlled by STOP signs, or traffic control signals that allow permissive turn movements across the tracks. A blank-out sign displays its message only once activated; the rest of the time the sign is blank. An alternative to blank-out signs would be an exclusive traffic control signal phase used in combination with a NO TURN ON RED sign (Figure A-5).

Figure A-4: MUTCD Signs R3-1a and R3-2a (Source: MUTCD 2003)

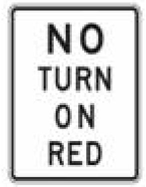


Figure A-5: MUTCD Sign R10-11a (Source: MUTCD 2003)

LIGHT RAIL ONLY LANE signs are also used to help other drivers acknowledge that the lane is reserved for light rail operations. These signs should be used where use is restricted only to light rail.

For light rail, MUTCD guidelines state that the Standard Highway-Rail Crossing Advance Warning signs should be used at every intersection with highway and at-grade crossings except under the following conditions:

A) "On an approach to a highway-light rail transit grade crossing from a T-intersection with a parallel highway, if the distance from the edge of the track to the edge of the parallel roadway is less than 100 ft (30 m), and signs (W10-3, MUTCD) are used on both approaches of the parallel highway; or

B) on low-volume, low-speed highways crossing major spurs or other tracks that are infrequently used and are flagged by transit crews; or

C) in business districts where active highway-light rail transit grade crossing traffic control devices are in use; or

D) where physical conditions do not permit even a partially effective display of sign."

Pavement Markings

Pavement markings are also suggested for light rail crossings under the guidelines of the MUTCD. Identical markings should be placed in each approach lane. The markings should be retroflectorized white. Pavement markings are not required if the traveling speed of the light rail vehicles is less than 40 mph (60 km/h). In Miami-Dade, pavement markings are used at the approach of intersections on the busway to show the busway is a "BUS ONLY" facility (Figure A-6) for drivers of automobiles that may consider making a turn onto the busway.

Figure A-6: Miami-Dade Busway Pavement Markings

Active Control Devices

Active traffic control devices help alert drivers of approaching light rail (or other specific mode). Active traffic control devices include flashing lights, traffic control signals, gate systems, automatic gates, and actuated blank-out and variable message signs (previously discussed).

Flashing Lights

Flashing lights should be used if the crossing is at another location other than an intersection, and where light rail transit speeds exceed 25 mph (40 km/h). Audible devices may also be used in conjunction with flashing lights. According to MUTCD, traffic control signals may be used in place of flashing light signals under the following conditions:

A) At highway-light rail transit crossings within highway-highway intersections where light rail speeds do not exceed 35 mph (60 km/h); and

B) If the crossing is somewhere other than an intersection, where the roadway volume is low and light rail speeds do not exceed 25 mph (40 km/h).

Gates

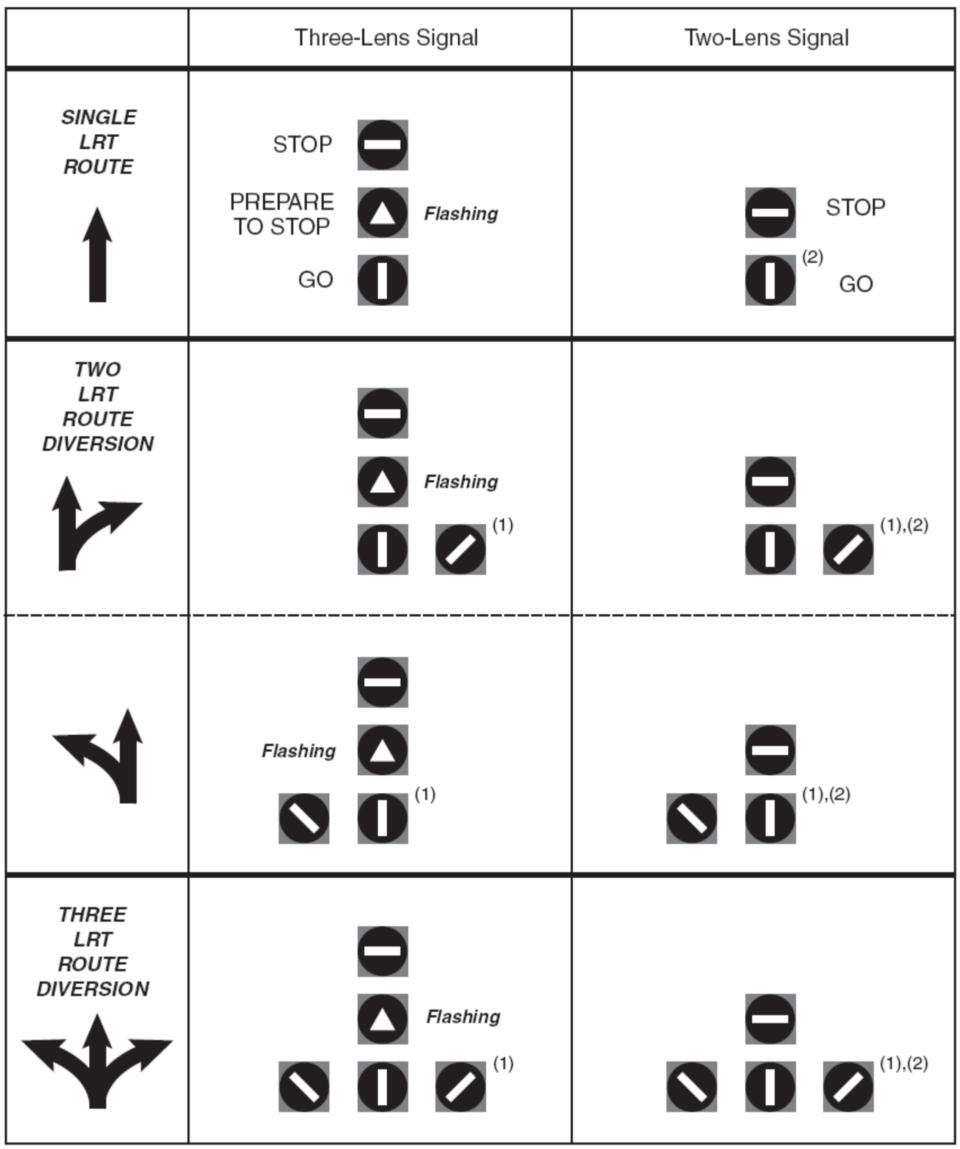
Automatic gates are accompanied by flashing light signals and are used in semi exclusive alignments where light rail speeds exceed 35 mph (60 km/h). Alternatives for the use of gates, such as traffic signal controls, may be used based on the situation (speed of vehicles, type of intersection, etc.).

Traffic Signals

Particular guidelines regarding traffic signalization have been determined for use at grade crossings. When an at-grade crossing exists within a signalized intersection, separately controlled turn phases should be provided. If a signalized intersection located within 200 ft (60 m) is preempted, all turning movements toward the highway-light rail transit grade should cease.

TCRP Report 90 (1) recommended that traffic signal displays for BRT systems should use white bar signal indicators since BRT vehicles are essentially LRVs vehicles with rubber wheels.

The report notes that they are applicable where buses operate (1) along median arterial busways, (2) along at-grade busways on separate right-of-way, and (3) in queue bypass lanes. The MUTCD notes that white bar signal indicators should be positioned so that they are not visible to motorists, pedestrians and bicyclists. They should be separated either vertically or horizontally from the nearest standard traffic signal by at least three feet *(6)*. White bar indications as recommended for LRT are pictured in Figure A-7. There are two different options for a light rail signal, a three-lens signal, and a two-lens signal. For the three-lens signal there is an additional lens specifically for the flashing "Prepare to Stop" phase. For the two-lens signal, the "Go" signal can also flash during the "Prepare to Stop" phase.



Notes:
All aspects (or signal indications) are white.
(1) Could be in single housing.
(2) "Go" lens may be used in flashing mode to indicate "prepare to stop".

Figure A- 7: Light Rail Signal Indication (Source: MUTCD)

OPERATIONAL ISSUES

Signal Priority

Transit signal priority (TSP) is a method that can be used to assist in the operation of buses along busways. Transit Signal Priority (TSP) is a cost-effective technology used to improve transit vehicle reliability and travel times. It is increasingly included as a key element of regional ITS developments and has become an important aspect of Bus Rapid Transit systems. Signal priority is used to assist in schedule adherence, reduced travel times, and better quality of service by changing the normal traffic signal process to better accommodate transit vehicles. It can be implemented in a number of ways, including green extension, early start/red truncation, phase skipping, compensation, conditional, and unconditional *(7)*. The type of signal priority system used should be dependent upon each system's characteristics and objectives.

- Green extension – extending the green phase beyond the normal setting to allow the bus a longer period of time to cross through the intersection.
- Early start/red truncation – advances the bus street green phase by prematurely ending all other non-bus phases.
- Phase skipping – to facilitate the bus priority phase, other non-priority phases from the normal sequence may be skipped, allowing the bus priority phase to occur again earlier than programmed.
- Compensation – Time lost to non-bus traffic may be compensated in the following cycle to alleviate disturbance to the flow of non-bus traffic.
- Conditional – specific conditions must be met in order for TSP to be activated for the bus.
- Unconditional – TSP is granted for the bus each time that it is requested.

While the benefits of TSP are noted, certain studies have found that TSP for buses may not have the desired effect on traffic at nearby intersections. In an evaluation of TSP strategies for buses in Ann Arbor, Michigan *(7)*, it was found that the bus priority provided little benefit to the corridor that was studied. The priority resulted in an increase in vehicle and person travel times and delays. It was further determined that as the occurrence of TSP increased, so did the delay in the transportation network. It was argued that the overall benefits that were gained by the buses did not counter the negative effects experienced by other vehicular traffic. In addition, bus headways of less than 15 minutes were found to be necessary to justify the provision of TSP for buses. The best combination of TSP strategies, i.e., having the least effect on other vehicular traffic, was of green extension and early start/red truncation.

The location of intersections in relation with each other has an effect on the operational conditions along a busway. A study conducted of the Miami-Dade Busway *(8)* found that a single traffic signal controller that controls both intersections as a single intersection is the best solution for issues that may arise with traffic among closely located intersections. Among closely located intersections, three conditions may occur. These include:

- Queue overflows – queues that build up at another intersection may overflow into another intersection, blocking some of the approaches.

- Safe stopping distance – adequate stopping distances may not exist between the two.
- Safe crossing gap – buses require larger gaps because of their operational characteristics. Traffic flows on a cross street may not provide the needed gaps.

With a single traffic controller that is run by traffic controller software with embedded internal clearances, vehicular traffic delays would be minimized by enabling the cross street traffic to clear both intersections at the same time. This may be accomplished by controlling the cross streets by a split-phasing operation.

In Miami-Dade, additional operational considerations were made due to the characteristics of one intersection. The intersection had six approaches, and was experiencing large delays because of the large cycle lengths that were needed. In order to alleviate this problem, a number of provisions were made. These provisions are listed below.

- Implementation of a semi-priority for the green phase for buses. This priority is conditional, however, and is granted only when U.S. 1 (a major arterial running parallel to the busway) has a green phase.
- The use of green/red arrow signals at the southbound right-turn lane at U.S. 1 was introduced, which only allows this traffic flow to move when there are no buses in the busway intersection.

TCRP Report 90 (1) also identified methods for adjusting signal timing at signalized intersections used by BRT to improve traffic flow, bus speeds, and reliability. The report outlines the following five techniques:

- Passive Priority Techniques: Modify existing signal operation through minimizing the number of phases, shortening cycle lengths, and maximizing green times.
- Active Priority Techniques: Extend or advance green time for oncoming buses within established cycles
- Real-Time Techniques: Consider real-time arrivals of automobiles and buses at individual intersections or a network of intersections.
- Preemption: Changes the existing signal timing to provide a clear path for oncoming buses.
- Special Phases: Special phases can be used when there is a conflict between BRT and vehicle movements. Such conflicts include a turn from a median arterial busway, a complex intersection, or a turnaround. Special phases can be either pre-timed or actuated.

Table A-2, extracted from *TCRP 90 (1),* further describes each of these techniques and the types of treatments that are included in each.

Table A- 2: Signal Treatments to Accommodate BRT (Source: *TCRP Report 90*)

Treatment	Description
Passive Priority	
Adjust Cycle Length	Reduce cycle lengths at isolated intersections to benefit buses
Split Phases	Introduce special phases at the intersection for the bus movement while maintaining the original cycle length
Areawide Timing Plans	Preferential progression for buses through signal offsets
Bypass Metered Signals	Buses use special reserved lanes, special signal phases, or are rerouted to nonmetered signals
Adjust Phase Length	Increased green time for approaches with buses
Active Priority	
Green Extension	Increase phase time for current bus phase
Early Start (Red Truncation)	Reduce other phase times to return to green for buses earlier
Special Phase	Addition of a bus phase
Phase Suppression	Skipped nonpriority phases
Real-Time Priority	
Delay-Optimizing Control	Signal timing changes to reduce overall person delay
Network Control	Signal timing changes considering the overall system performance
Preemption	Current phase terminated and signal returns to bus phase

Left and Right Turn Restrictions

TCRP Report 90 (1) discusses the use of turn restrictions to increase the speed and reliability of BRT systems by preserving capacity and reducing delay. Turn restrictions can vary from the time of day they are in effect (all day, 7 a.m. to 7 p.m., peak periods, etc) and are generally applied to all vehicles except BRT.

Right turn restrictions are usually implemented when BRT operates in mixed traffic, curb bus lanes, interior bus lanes, and where both right vehicular turn and pedestrian volumes are heavy. Equation A-1 can be used to estimate the increase in BRT travel time gained from implementing right turn restrictions:

$$\Delta t = rpt_s / L \qquad [A-1]$$

Where:

Δt = green time to be gained per cycle
r = right turns per cycle (peak 15 minutes)
p = conflicting pedestrians per cycle
t_s = time per pedestrian
L = number of pedestrian channels in crosswalk

Left-turn restrictions are possible when designated left-turn lanes are provided. In general, however, left-turns cannot be restricted whenever the left turn movements share lanes with through traffic. Left turn restrictions can be implemented when the there are median arterial busways (or provide protected signal phasing), curb lanes, dual curb lanes, interior bus lanes, median bus lanes, contra flow lanes, and buses operating in mixed traffic

Another option is to employee alternate left-turn lane strategies including "Michigan U-turns" and "Jersey Jug Handles". These eliminate direct left turn at intersection, converting each left turn movement into a combination of other movements away from the intersection.

TCRP Report 17 discusses the relationship between safety and turn restriction violations at light rail systems *(3)*. Similar problems are encountered at busway intersections. The greatest percentage of collisions on light rail systems operating up to 35 mph occurs due to illegal turning movements of motor vehicles. In addition, turning collisions are also more severe types of motor vehicle/LRV collisions.

There are several possible treatment combinations that can be used to deter left and right turn movements across LRT tracks depending on the intersection alignment and traffic control device. Two possible treatments are internally illuminated "Train Approaching" signs and "No Left/Right Turn" signs. Table A-3 presents a summary of the recommended alignment type and intersection traffic control devices that each of the signs should be applied to.

Table A-3: Use of Internally Illuminated Signs for Parallel Traffic Turning Across LRT Tracks

(Source: TCRP Report 17: Integration of Light Rail Transit into City Streets, Pg 74)

ALIGNMENT TYPE	INTERSECTION TRAFFIC CONTROL DEVICE	"NO LEFT/RIGHT TURN" SIGN[a]	"TRAIN" SIGN FOR LEFT/RIGHT TURNS[a]
Semi-Exclusive Gated	Stop[c]	Should	May
	Traffic Signal w/o Arrow[d]	Should[b]	May
	Traffic Signal w/Arrow[e]	Not Recommended	May
Semi-Exclusive Non-Gated	Stop[c]	Should	May
	Traffic Signal w/o Arrow[d]	Should[b]	May
	Traffic Signal w/Arrow[e]	Not Recommended	Should

[a] Left-turn signs are for median and side-aligned LRT alignments, right-turn signs are for side-aligned LRT alignments only

[b] Alternatively, an all-red phase for motor vehicles and pedestrians may be used in combination with NO TURN ON RED (R10-11a) signs.

[c] "Stop" refers to a stop sign-controlled intersection

[d] "w/o Arrow" refers to a signalized intersection where the turning traffic has no red arrow displayed when an LRV is approaching but has either a steady green ball, a red ball, or a flashing red ball displayed

[e] "w/Arrow" refers to a signalized intersection at which the turning traffic has a red arrow displayed when an LRV is approaching When a turn arrow traffic signal indication is used, an exclusive turn lane should be provided

BUSWAY CASE STUDY - CRASH ANALYSIS IN MIAMI-DADE

In August 2001, the "South Miami-Dade Busway Safety Study" was completed *(9)*. DMJM Harris and FR Aleman and Associates conducted the study in response to a number of crashes occurring along the busway. From February 1997 to November 2000, 67 crashes that involved buses were recorded at busway intersections. Seventy three percent of the recorded crashes resulted in injuries and two in fatalities. The study found that a greater likelihood (seven times) of crashes existed at busway intersections that were independent of other intersections. The intersection with the highest number of crashes was SW 186th Street, with 0.815 crashes per million vehicles entering (MVE).

At intersections that were shared between the busway and US 1, a high number of crashes were the result of right turn on red violations. A study conducted at three intersections that were susceptible to right turn on red violations found that approximately 12.5 percent of drivers were in violation of the turn restrictions.

Signage along the busway was also a consideration of the study. When the report was completed, the location of existing crossway signs was more than 100 feet from the bus crossings. This placement was inconsistent with the guidelines from MUTCD, which suggest placing crossway signs at intersections or as close as possible. The visibility of signs along the corridor was also a consideration. Vegetation was overgrown along areas of the busway, thereby restricting the visibility for some of the signs.

The study also determined that crashes were seven times more likely when the advanced loop detectors, installed for signal priority, were enabled than when they were disabled. When the loop detectors were activated, buses were able to receive a green signal and continue along the busway at the corridor speed of 45 m.p.h.

Recommended Countermeasures

The report provided recommendations as "Crash Countermeasures" for the short, medium and long-term. Some of the provided recommendations follow.

Short-Term Recommendations

- Modify loop detectors installed at near side bus stops;
- Modify the advanced loop operations for a bus approach speed of 15 m.p.h.;
- Remove overgrown vegetation;
- Install additional advance Busway Crossing Warning signs.

Medium-Term Recommendations

- Install a textured road surface at isolated Busway intersections;
- Install in-roadway amber-red lights;
- Install a raised central island on cross street approaches of isolated intersections.

Long-Term Recommendations

- Install flashing signals, such as those used for moveable bridges and railroad crossings;
- Install automatic gates;
- Install grade separated intersections.

OTHER INDUSTRY EXPERIENCE

Extensive efforts in the planning and operation of systems to avoid accidents are made on behalf of agencies. While the occurrence of incidents cannot be eliminated, a safe operating environment is a main concern for systems. A number of cities with light rail systems have made notable attempts to alleviate the occurrence of problems.

The Metropolitan Transit Authority of Harris County's METRORail, which began operation in 2004, has provided reliable transportation to patrons throughout the city. As ridership numbers have increased, however, so have the number of collisions. During the month of March 2004, 11 collisions occurred. Directly following, METRORail implemented changes in the safety program and has experienced a decrease in the number of collisions that has occurred. In an effort to achieve this goal, focus has been placed on enforcement, engineering, and education *(10)*. According to researchers at the Texas Transportation Institute, focusing on these three issues is important to improving the safety of any transportation mode.

Enforcement

The violation of traffic laws relating to highway-rail crossings is the most significant reason in grade crossing incidents *(11)*. A number of enforcement methods can be implemented that may deter drivers of motor vehicles from failing to comply with laws. One method is to increase the presence of law enforcement officials at designated areas. Houston's METRORail police force is now able to actively enforce jaywalking and motor vehicle moving violations with warnings and citations. Since enforcement has increased, the number of illegal turns along the light rail line has decreased. A similar relationship occurred in Los Angeles. In 1992, the Sheriff's Transit Services Bureau in Los Angeles increased enforcement at particular grade crossings. Within 90 days, 7,760 citations were written, which encouraged officials to continue funding for six officers to patrol grade crossings.

Another method of enforcement is the use of automated technology, such as video cameras (a picture is taken of the license plate of a vehicle running a red light). A pilot study conducted of Los Angeles' light rail system at two grade crossings found that violations were reduced 92 and 78 percent within a few months for each respective location *(12)*.

Engineering

System design and employed technologies along grade crossings are engineering aspects that affect the safety conditions. Houston's METRORail took additional measures for safety improvements along their system. Additional signs and pavement markings were added to assist in directing street traffic along the light rail line. Signs that once lit up with "Train Approaching" now flash as well, which are more effective at getting the attention of drivers. METRORail also reconfigured their traffic signal cycle so that they are in an all red phase as trains pass.

The Utah Transit Authority (UTA) has also taken steps to lessen the likelihood of collisions on their light rail system. Many of their grade crossings have gates, bells and lights. The majority of intersections have a median and side-street gate. In addition, pedestrian gates are placed behind sidewalks so pedestrians cannot cross the intersection. The implementation of each of these measures has resulted in fewer train collisions.

The Los Angeles Metro Blue Line (MBL) designed their safety measures in accordance with standard guidelines and requirements. Additional improvements were made, however, such as installation of four-quadrant gates, street and traffic signal system improvements, pedestrian gates, and the testing of a train operator actuated wayside horn system *(13)*. The four-quadrant crossing gates were implemented in crossings where vehicles had to cross three to four tracks. The need for the gates is greater with these tracks, as motorists are able to maneuver around lowered gates with greater ease than those with a smaller intersection. Without four-quadrant gates, motorists are also able to make left turns from streets that run parallel to tracks and maneuver around lowered gates.

Street and traffic signal improvements for the MBL included the installation of separate left turn lanes, signal phases, and red left turn arrows at five intersections. Providing separate lanes for motorists wanting to turn left gives motorists a place to waiting before making a turn across the tracks. Raised concrete medians, centerline curbs, or plastic delineators were also constructed at several MBL crossings without disrupting traffic running parallel to the tracks. Medians or center line curbs restrict the ability of motorists to drive around lowered gates. Additionally, overhead traffic signals for the MBL, which were often easily confused with signals for general traffic, were programmed so motorists turning left were not able to see the through signal for the transit system *(14)*.

Education

According to the National Transportation Safety Board (NTSB), the motoring public does not fully understand the risk level at passive crossings. Another study conducted in 1998 by the University of Tennessee found that 75.6 percent of respondents answered a question regarding the actions of motorists approaching a crossing without railroad signals incorrectly *(15)*. These studies show that the need for increased education of the public for transit is apparent.

Several organizations provide highway safety education, including the American Automobile Association (AAA), Operation Lifesaver (a not-for-profit organization that provides information about grade crossing safety), and the Professional Truck Drivers Institute of American (PTDIA). A review conducted by the NTSB found that these organizations provided little information regarding the actions required of drivers or the dangers at passive grade crossings *(3)*. In providing suggestions to remedy this problem, the NTSB made a couple of recommendations. The recommendations were to include sufficient information regarding passive grade crossings, ensure that the topic is covered in state written driver examinations, and to design a national media campaign to inform motorists of newly installed stop signs at passive grade crossings and of their importance.

In Houston, efforts to educate the public were extended. Public service announcements have been made, and safety literature has been widely distributed. In addition, a number of TV commercials focusing on driver and pedestrian safety were aired on television *(10)*. In Los Angeles, efforts to educate the public about safety were made with the opening of the Blue Line as well. The safety campaign targeted those that lived within a five-mile radius from the system. Similar to the experience in Houston, a number of videos were also aired on local TV.

One other important aspect to consider when dealing with safety issues of grade crossings is the existence of strong relationships between the different agencies involved in the effort. Traffic-transit operation integration is an essential component of the planning design and operation of BRT running ways. Close working relationships between traffic engineers and transit planners is essential in developing bus lane and busway designs, locating bus stops, and applying appropriate traffic controls. In a study conducted by Korve Engineering *(14)* to provide an overview of at-grade operations being addressed by light rail, researchers found that good interjurisdictional relationships between cities and transit agencies were important for all of the LRT systems contacted. Institutional relationships in new or growing systems occur if there is significant regional political support for transit. The study also found that institutional relationships are necessary for agencies that have only been operating at-grade transit for a few years, and those where expansion of the system is expected. Agencies that have already experienced these growing pains are more likely to focus on the operation and maintenance of the system.

Other relationships that are necessary to implement and maintain a successful system may be between the transit agency and law enforcement. In Los Angeles, the Metro works closely with the Los Angeles County Sheriff's Department *(13)*. With this relationship, Metro is able to use the department's photo enforcement system for the Blue Line. Other relationships that are proven beneficial are those between the transit agency and traffic control engineers. Working as partners to facilitate the flow of traffic and ensuring safety is more likely to benefit the transit system than if not.

Pedestrians

The safety of pedestrians is also a concern at many at-grade crossings. Incidents that involve pedestrians at crossings may not effectively be mitigated through conventional vehicular traffic control. Additional measures should be made to ensure that the safety of pedestrians is considered. Some of these measures include the placement of pedestrian gates and additional signage.

In 1998, the Westside MAX extension of TriMet in Portland, Oregon opened, significantly increasing the number of at-grade crossings of the system *(16)*. Coincidental with the opening of the extension, several serious incidents involving pedestrians and light rail vehicles occurred, regardless of well-marked "No Trespassing" signage in certain locations. TriMet's operating practices and track crossing designs incorporated the current standards in the transit industry, yet an extensive review for the system itself was conducted to identify enhancements that may reduce the occurrence of risky behavior. A number of enhancements were then introduced.

TriMet enhanced the safety treatments to improve the safety for pedestrians. Treatments added were additional signage, swing gates, channeling, detectable warnings, "Stop Here" markings, automatic pedestrian gates, and audible-visual warning devices. Although measuring the effects of these enhancements is difficult, TriMet concluded that pedestrian awareness increased with the implementation of certain enhancements. Because of this, TriMet developed "Light Rail Crossing Safety" criteria. The criteria are to serve as a guide for future management, design, and planning of TriMet projects.

SUMMARY

Based on the review of available literature pertaining to safety at-grade crossings, particular considerations must be made when designing a system and in planning actions to be made to ensure the safety of transit patrons, motorists, and pedestrians. Industry experience has shown that measures that are taken in addition to current industry standards (i.e., MUTCD and AASHTO's Green Book) increase the success of a transit system with at-grade crossings in achieving a safer environment. In Miami, it was found that if current industry standards are not implemented, there is an increased possibility of problems occurring *(17)*. As shown in locations such as Houston and Los Angeles, it is not only important to focus on engineering aspects, but to also place value of the enforcement of laws at-grade crossings and to make efforts to increase the knowledge of the general public about these systems. These systems provided additional police presence at the crossings either through the use of actual officers issuing citations, or automated technologies, and made efforts to educate the public through commercials that were aired on public television. Overall it has been found that the success of transit systems has been based on a number of factors. With the increased number of transit agencies considering the implementation of BRT systems in the U.S. and the use of busways within these systems, particular attention must be made to the experiences of the transit industry. With careful consideration of these experiences, and efforts to incorporate enforcement and education into the planning, many systems will likely witness positive implementations of BRT's systems operating along busways.

REFERENCES

1. Levinson, H., S. Zimmerman, J. Clinger, S. Rutherford, R.L. Smith, J. Cracknell, and R. Soberman. *TCRP Report 90*: *Bus Rapid Transit, Vol. 1: Case Studies in Bus Rapid Transit* and *Vol. 2: Implementation Guidelines*. Transportation Research Board of the National Academies, Washington, D.C., 2003.
2. Shen, D., H. Elbadrawi, F. Zhao, and D. Ospina. *At-grade Busway Planning Guide.* Florida International University, 1998.
3. Korve, Hans W. *TCRP Report 17: Integration of Light Rail Transit into City Streets.* Transportation Research Board, National Research Council, Washington, D.C., 1996.
4. Korve, H.W., B.D. Ogden, J.T. Siques; D.M. Mansel, H.A. Richards, S. Gilbert, E. Boni, M. Butchko, J.C. Stutts, and R.G. Hughes. *TCRP Report 69: Light Rail Service: Pedestrian and Vehicle Safety,* Transportation Research Board, National Research Council, Washington, D.C., 2001.
5. American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets,* Washington, D.C. 2001.
6. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, Washington, D.C. 2003.
7. Al-Sahili, K.A., and W.C. Taylor. “Evaluation of Bus Priority Signal Strategies in Ann Arbor, Michigan,” *Transportation Research Record 1554,* National Research Council, Washington, D.C., 1996, pp. 74-79.
8. Imada, T., “Traffic Control of Closely Located Intersections: The US 1 Busway Experience,” ITE Journal on the Web, p. 81-84, May 2001.
9. DMJM+Harris and F.R. Aleman. “South Miami-Dade Busway Safety Study,” March 2001.
10. Sage, J. “How Light Rail Systems Have Enhanced Grade Crossing Safety,” *METRO*, 2005.
11. AAR. Railroad Industry Grade Crossing Policy Agenda, developed 1994, revised 1998.
12. Insurance Institute for Highway Safety. “FHWA addresses crashes at rail crossings but misses the potential of cameras to reduce gate signal violations,” *Status Report*, Volume 38, No. 3, March 15, 2003.
13. Meadow, L. “Los Angeles Metro Blue Line Light Rail Safety Issues,” *Transportation Research Record 1433,* Transportation Research Board, National Research Council, Washington, D.C., 1994, pp. 123-133.
14. Korve, H.W., and M.M. Jones. “Overview of Light Rail At-Grade Crossing Operations in Central Business District Environments,” *Transportation Research Record 1433,* Transportation Research Board, National Research Council, Washington, D.C., 1994, pp. 134-142.
15. Richards, Stephen H., and K.W. Heatherington. “Motorist Understanding of Railroad-Highway Grade Crossing Traffic Control Devices and Associated Traffic Laws,” *Transportation Research Record 1160*, Transportation Research Board, National Research Council, Washington, D.C., 1988, pp. 52-59.

16. Irwin, Don. "Safety Criteria for Light Rail Pedestrian Crossings," *Transportation Research Circular E-C058,* Transportation Research Board of the National Academies, Washington, D.C., 2003, pp. 266-288.

17. DMJM+Harris and F.R. Aleman and Associates, "South Miami-Dade Busway Safety Study – Volume 1", August 2001.

APPENDIX B
SYNTHESIS OF PRACTICE

INTRODUCTION

The objective of this synthesis of practice is to evaluate and document the state-of-the-practice information on at-grade crossings at exclusive busways, as it is applicable to the U.S. The synthesis is based largely on the literature review and a survey of practice. It presents material that was current as of May 2005.

Literature Review

The literature review, included as Appendix A, was used to provide input for the synthesis of the practice.

Survey of Practice

Detailed telephone surveys were conducted of eleven busway systems planned or currently operating in the United States or Canada and one light rail system. For each busway system, representatives from both the bus operating agency and the highway agency were interviewed.

Existing Busways in the United States

The survey included four systems that are currently operating in the United States, including one transit mall. Each of these systems is briefly described in the following sections.

Lynx LYMMO, Orlando, Florida. The Lynx LYMMO system serves downtown Orlando along a three-mile circular route. The buses run on physically separated busways within the street ROW, on a combination of median, same-side, and contra flow lanes. The exclusive lanes are separated from general traffic lanes either with a raised concrete median or a double row of raised reflective ceramic pavement markers embedded in the asphalt. There are a total of 23 at-grade intersections along the busway route.

South Miami-Dade Busway, Miami, Florida. The South Miami-Dade Busway is an 8.2-mile long exclusive busway that runs parallel to and directly west of US 1, a heavily traveled six lane divided road that carries over 90,000 vehicles a day. The distance between the busway and US 1 varies from as close as 50 feet in the northern sections to as far as 400 hundred feet in the southern sections. There are 19 at-grade intersections. It is scheduled to be lengthened an additional 20 miles to the south, extending to 264th Street in the spring of 2005, and then to its terminus at 334th Street in 2007.

Denver Transit Mall, Denver, Colorado. The 16th Street Transit and Pedestrian Mall in Denver is a 1.4 mile busway in downtown Denver. There are 17 signalized intersections along the busway. The busway operates in a city street right-of-way that was once a five lane downtown street used for general traffic. The buses operate in two single bidirectional lanes with pedestrian medians in between the two lanes, and very wide sidewalks between the buildings lining the street and the busway lanes.

East, West and South Busways Pittsburgh, Pennsylvania. The Port Authority of Allegheny County, also known as PAT, owns and operates three dedicated busways in the Pittsburgh, Pennsylvania region including the South Busway, the Martin Luther King East Busway, and the West Busway. Collectively, there are 18 miles of busway on the three lines.

With the exception of bus entry and exit points, there is only one at-grade intersection with highways. The busways operate on two-lane concrete roadways constructed primarily on separated right-of-way for exclusive use by public transportation vehicles and select emergency and police vehicles.

Existing Busways in Canada

The survey included two busway systems in operation in Canada. These systems are described in the following sections.

#98 B-Line in Vancouver, British Columbia, Canada. The #98 B-line is a Bus Rapid Transit system that connects downtown Vancouver, Richmond city center and Vancouver International Airport along a 9 mile route. The route is composed of a variety of different alignment including 1.4 miles of separated median busway. The median busway segment has 7 southbound at-grade intersections and 8 northbound at-grade intersections.

Ottawa Transitway, Ontario, Canada. The Ottawa Transitway System links downtown Ottawa with surrounding activity centers. In total, the transitway is almost 40 miles in length with 16 miles of exclusive busway. There are three at-grade intersections along the exclusive busway segment, all of which have both highway and pedestrian traffic. Additionally, there are three pedestrian only crossings.

Planned Busways in the United States

The survey also included five planned busway systems in the United States. These systems are at various stages of planning, design, and construction. Each of these systems is briefly described in the following paragraphs.

New Britain – Hartford Busway, Connecticut. The New Britain – Hartford Busway is proposed to be a 9.5 mile exclusive busway running from New Britain to Hartford, roughly following the route of the I-84 corridor. Half of the two-lane busway route will use abandoned rail line ROW, while the other half will use parallel active AMTRAK service ROW. It would connect with freeways and city streets in New Britain, and with city streets in Downtown Hartford. The proposal is still in the design stage and is scheduled for implementation in 2010. A preliminary engineering study has recently been completed, which finalized the route alignment and indicated that there will be 4 at-grade signalized intersections.

San Francisco East Bay Area Busway, California. The proposed busway would operate between Berkeley, Oakland, and San Leandro is currently in the design stages. The 18-mile long route would run from the UC Berkeley Campus through a dense urban environment, roughly following the route of an abandoned trolley line including 12 to 13 miles of two lane median busway to downtown Oakland and continuing to the Bay Fair BART station in San Leandro. The number of at-grade intersections has not been determined.

LAMTA Orange Line, Los Angeles, California. The Metro Orange Line (MOL) is a 14.2-mile busway in the San Fernando Valley area of the County of Los Angeles. When completed in the fall of 2005, it will connect the mature suburbs and urbanized areas as far as the Warner Center with the North Hollywood Metrorail Station. The MOL right-of-way is exclusive within the median of a street right-of-way for approximately five miles, where it operates within an 80 foot space previously occupied by rail operations. In the remaining nine miles of the corridor, the MOL will operate in a 100-foot former railroad right-of-way. There are 35 at-grade intersections along the 14-mile corridor, most of which will be signalized.

Euclid Corridor, Cleveland, Ohio. The Euclid Avenue Bus Rapid Transit corridor, also referred to as the Silver Line, is scheduled to be fully operational by 2008, with portions of it in operation by 2007. This 7.1-mile corridor will provide BRT service in an east-west direction along Euclid Avenue. In one section, bus-only lanes will be flanked by a central landscaped median and separated from a single traffic lane each way by a one-foot rumble strip. In another section, buses will operate in the left lane of the four-lane divided corridor. This left lane will be for exclusive use by transit vehicles and emergency vehicles, but they will not be physically separated from the other lanes of the arterial. A one-foot wide rumble strip will be placed between the right lanes and the exclusive transit lane.

EmX Bus Rapid Transit, Eugene Oregon. Eugene's Lane Transit District (LTD) aims to implement a major network of Bus Rapid Transit routes around the city. This long-term proposal for incremental implementation of BRT along different travel corridors is titled "Progressive Corridor Enhancement", and is branded as the "EmX". The exclusive busway employs median transit lanes for approximately 1.25 miles and curbside transit lanes for around 1 mile. Separation of the transitway from the regular traffic lanes varies along the route from painted line only to full physical separation using curbing. Most of the transitway has been designed as a single lane, two-way transitway, which means that, due to corridor width restrictions, two-way BRT traffic must be accommodated on only one lane. The transitway has been designed so that buses will pass each other at stations. In one instance an exclusive "left turn pocket" is planned to allow for passing maneuvers. There are a total of 30 intersections along the route, with 19 intersections on the exclusive busway portions.

Light Rail System — Portland, Oregon

The number of busways in the United States and in Canada is limited. Although there are many differences between light rail systems and busways, some information can be drawn from the experiences of light rail systems and applied to busways. The Portland Tri-Met Rail System was selected for this purpose because it operates similar to a BRT system.

The Tri-Met Light Rail system in Portland, Oregon, known as "MAX", has four lines totaling 44 miles. This light rail system connects Portland, Gresham, Beaverton, Hillsboro, and the Portland International Airport. The light rail system operates at grade through most of the service area, while also traveling through deep tunnels for three miles on the Westside line. It operates in mixed traffic through the heart of downtown Portland, and on limited access right-of-way in the more suburban areas it serves. There are 136 at-grade crossings of the MAX lines. While there is no danger of other vehicles trying to operate along the tracks of a train system as is the case with dedicated busway corridors, there are other intersection issues that are similar between light rail and busway operations.

The detailed findings of the survey of practice were submitted with the interim report. Specific findings from the survey are discussed in the following sections as they relate to the various elements.

TRAFFIC CONTROL DEVICES

Traffic control devices include all signs, signals, markings, and other devices that are used to regulate, warn, or guide buses, motorists, pedestrians, and bicycles at intersections of at-grade busways.

Unauthorized Entry to Busway

Some agencies reported occurrences of unauthorized entry onto the busways by vehicles, however, of the agencies surveyed, most did not identify unauthorized entry to busways as a major safety problem. The bus agency in Orlando has experienced many unauthorized entries but attributed this to motorist confusion and a general unfamiliarity with one-way streets in an urban setting.

In addition to unauthorized entry vehicles, pedestrians may also enter the busway illegally. In Vancouver, pedestrians have crossed the median busway illegally at midblock and, in some cases, pedestrians have been observed walking along the median busway in order to transfer between routes.

There are various traffic control devices that can be used to deter unauthorized entry to busways by communicating to motorists or non-motorized users that the facilities are only for use by transit buses. These traffic control devices include signs, pavement markings, and colored or textured pavements. However, many had employed traffic control devices to deter unauthorized entry.

Preventing unauthorized vehicle entry at intersections usually entails prohibiting one or more movements at the intersection. Drivers are familiar with prohibitions on left and right turns at traditional intersections. The agency that operates the busway in Ottawa found that it was hard to restrict straight through movements at the intersection because it violates drivers' expectations.

Signs

The agencies that were surveyed employed a variety of signs to deter unauthorized entry. The Manual on Uniform Traffic Control Devices (MUTCD) provides a variety of turn prohibition signs (R3-1 through R3-4, R3-18). It also provides a variety of traffic prohibition signs such as the DO NOT ENTER sign (R5-1) and the WRONG WAY sign (R5-1a).

South Miami-Dade and Ottawa reported that visual clutter at the intersections detracts from the signing used. Visual clutter decreases the conspicuity of the sign. In Orlando, regulatory signs to deter unauthorized entry consist primarily of turning restriction and "Do Not Enter" signs. However, the signs often go unnoticed by the motorists. This is particularly the case when the busway runs parallel to general use lanes. Although not specifically identified as a cause during the interview, this might also be the result of visual clutter.

In Ottawa, most unauthorized entry onto the busway is a result of motorists who are unfamiliar with that part of the city violating the turn restrictions. Motorists usually realize quickly that the busway is not a normal roadway. Within the busway, wayward signing is employed to assist motorists who have illegally entered the busway to exit the system safely.

Pavement Markings

Some agencies including Lynx in Orlando and Miami-Dade County Transit reported using pavement markings that read "BUS ONLY" at the entrance points to busways.

Colored and Textured Pavement

Although not commonly used in the United States, color and textured pavements have been used in Australia and in France to deter unauthorized entry. Applications in the U.S. include the Lynx Lymmo busway in Orlando. The busway utilizes unique pavement and texturing to discourage motorists from entering the busway. The representative of Lynx stated that it is important to use creative means to differentiate the surface of the busway from general travel lanes.

The planned busway in Eugene will employ concrete running ways for the busway. Since the surrounding road surfaces are asphalt, there will be a visual indicator that the busway is not for general traffic.

Other Devices

The system operators in Ottawa experimented with using staffed gates to control access at one intersection along their busway. However, this was abandoned due to staffing limitation. Automatic gates are currently being proposed for the South Miami-Dade system. On the proposed Hartford – New Britain Busway, in areas where the busway will run along an existing Amtrak corridor, automatic gates will be used to control traffic when buses cross the roadway.

The only busway in the United States that currently uses gates is the Pittsburgh busway. The busway only has one true at-grade intersection. It is an at-grade intersection with a county road where the busway runs parallel to an active rail line. The intersection is controlled by traffic lights and gates. There are also cross-bucks, signage, and street markings to alert drivers to the intersection. There is a loop detection system embedded in the intersecting county road. An approaching train pre-empts all movements at that intersection, causing the traffic signals to go red, while flashing red lights, bells, and gates are activated. Newer style gates also block pedestrian movements at the intersection.

The Portland Tri-Met light rail system has gates at 35 of the 135 crossings of the system. In addition to the gates, the crossings are equipped with warning signs, pavement markings flashing lights, and traffic signals. All of these elements are consistent with the MUTCD standards. There are 20 seconds of warning prior to the arrival of the train. There have been four accidents in 18 years at such intersections.

Channelization

Traffic control devices can be used to channelize motorists, buses, and non-motorized users at intersections. Design elements that are used for channelization are covered subsequently in this chapter in a separate section on geometric design.

Two agencies reporting using traffic control devices to assist movements in the intersection. Vancouver uses pavement markings nicknamed "cat tracks" to guide left turning vehicles in the intersection. Orlando uses raised pavement markers to separate vehicle and busway movements at intersections.

Pedestrian Control

Most of the surveyed agencies indicated that they had pedestrian and vehicle signals at intersections. Signalization was the primary form of traffic control device for pedestrians. No agencies that were surveyed used gating to control pedestrians.

Exclusive Pedestrian Crossings

A few of the busways have exclusive crossings for pedestrians and other non-motorized users to travel across the busway. The South Miami-Dade system has two such intersections. Ottawa has three intersections that are exclusively for pedestrians and non-motorized users to cross the busway. The Ottawa exclusive pedestrian intersections are not signalized. The bus agency noted that even if the intersection was signalized, pedestrians would not obey the signal. In Los Angeles, there are three mid-block crossings of the soon-to-be-opened busway for pedestrians. Two of these crossings are equipped with signals that are activated by motion detection. The third crossing is at a National Guard site. It is uncontrolled except for a warning sign provided for pedestrians. Pittsburgh has a pedestrian crossing at each station that allows for movement between platforms.

Pedestrian Control in Ottawa

Ottawa has three at-grade intersections of the highway with the busway. At these signalized intersections, pedestrian accommodation varies by intersection. At the Laurier intersection, the signal operates in a fixed time cycle so pedestrian phases are included every cycle. At the Lebreton Station, the signal operates in fixed time operation during the peak periods and the pedestrian phases are included every cycle. However, in the off-peak, pedestrians are required to activate the signal. At the Iris St. intersection, the pedestrian phase is fully actuated. The bus operating agency notes that pedestrians almost always cross the busway legs of the intersection without activating the pedestrian signal. This is attributed to the width of the transitway and the low volume of buses. The agency indicated that because of the low volume of pedestrians at this intersection, this non-compliance did not create a major safety problem.

Marked crosswalks are commonly used at intersections for pedestrians. However, Ottawa reported that they removed the crosswalk markings at one intersection out of concern for the safety of pedestrians. Pedestrians were crossing when they did not have the right of way at the intersection. The crosswalk markings were removed in response to this problem.

One potential problem with pedestrian crossings of busways is that removing crosswalk lines does not change the fact that under the vehicle code regulations of most states, vehicles are generally required to yield the right-of-way to pedestrians at unmarked crosswalks at unsignalized intersections. Presumably, this would include bus vehicles, so transit agencies might have a hard time providing buses with the legal right-of-way.

Pedestrian Control around and across the Denver Transit Mall

There is no physical separation between the transit mall and the parallel pedestrian sidewalk, so there is no need for designated midblock crossings. Additionally, the buses travel at low-speed along the mall. At the intersections with vehicle roadways, pedestrian activity is controlled by standard pedestrian signals and crosswalk markings.

Other Pedestrian Control

In the planned Euclid Corridor busway in Cleveland, Ohio, pedestrian countdown signals will be used at intersections. No other agencies were identified that plan to use or currently use pedestrian countdown signals.

Bus Control

The surveyed agencies differed in the type of signals that were used to control the buses. Some systems such as the busway in Ottawa, employed standard red/yellow/green traffic signal indications along busways. Other systems such as the LYMMO system in Orlando use light rail transit signal indications.

Light Rail Transit Signal Indication in Orlando

Because the LYMMO operates in places and directions contrary to other vehicular traffic, all bus movements at intersections are controlled by light rail transit signal indications. To prevent confusion, the bus-only signal heads are mounted directly over the bus-only lanes and use illuminated lunar white bars on a three-aspect display unit to signify Stop, Prepare to Go, and Go. The signals are loop actuated so that non-LYMMO buses using the bus-only lanes will get a signal. When a LYMMO vehicle approaches an intersection, a loop detector in the bus-only lane triggers the intersection to allow the vehicle to proceed either in its own signal phase (e.g. when making turns not otherwise permitted) or at the same time as other vehicular traffic is released when no conflicting traffic movements are permitted.

Coordination with Closely Spaced Signals in South Miami-Dade

Buses operating on the busway are governed by the signal system along US 1 which runs parallel to the busway. Many of the closely spaced intersections of the busway and US 1 operate as single signalized intersections. Originally, some of the intersections in the Southern section of the busway were operated as separate intersections from the closely spaced US 1 intersection. In response to a safety problem, these were altered to operate so that both intersections display red at the same time. Later, programmable visibility signal heads were installed on cross streets to prevent driver confusion between the busway and US 1 signal heads. This is discussed in more detail in this chapter in the section entitled “Reported Safety Performance.”

Signals for the busway display red unless loop detectors indicate an approaching bus. If the approaching bus can clear the intersection while US 1 through traffic continues to move as permitted by green lights, then the busway signals turn green. Otherwise, the busway traffic receives a red signal and must wait until the next cycle.

Bicycle Control

Vehicle signals at intersections also control bicyclists on the roadway. Additionally, there may be designated bicycle facilities that run parallel to or intersect busways at-grade. For example, the South Miami-Dade system has an 8-foot wide shared use path on the west side of the busway. Similarly, the planned system in the Euclid corridor has a bike lane near the curb. The traffic control of the bike lane or shared use path at the intersection with the busway is important to the safety of the crossing. At intersections with the busway in the South Miami-Dade system, the shared use path is controlled by a pedestrian signal.

Vehicle Control

Vehicles at intersections with busways can be controlled by traffic signals or by STOP or YIELD signs. Most of the agencies surveyed used traffic signals to control vehicles at at-grade intersections.

Some agencies reported that vehicles on parallel approaches to the busway could see the signals for the busway and confused these with their own. In Ottawa, louver screens were added to the busway signals to shield the view of the bus signals from the motorists. Supplemental signs were also installed that informed motorists that the buses will go first. In the South Miami-Dade system, programmable visibility signals are used to prevent vehicle from seeing the busway signals.

The planned busway in the Euclid corridor will employ light rail signal indications to control buses instead of standard signal indications so that motorists on the parallel approach are not confused.

Summary of Traffic Control Devices

The following provides a brief summary of the major issues related to traffic control devices.

Unauthorized Entry

- Unauthorized entry to busways was not identified as a major safety problem.
- Various traffic control devices such as signs, signal indications, and pavement markings have been employed effectively to deter unauthorized entry at intersections.
- Some agencies were concerned that visual clutter reduces the effectiveness of these traffic control devices, particularly signs.
- Differentiating the running way of the busway by using colored, textured, or a different type of surface (i.e., asphalt versus concrete) may be useful, particularly in dense urban areas.
- If unauthorized entry does occur, wayward signing in the busway may help motorists to leave the busway as soon as possible, minimizing the likelihood of being involved in a crash.
- Gating at busway intersections is only used at one intersection where it is combined with a railroad crossing.

Channelization

- Pavement markings and raised pavement markings are employed to guide and separate vehicle and busway movements at intersections.

Pedestrian Control

- Signalization is the primary form of traffic control device for pedestrians.
- No agencies that were surveyed used gating to control pedestrians.
- A few of the busways have exclusive crossings for pedestrians and other non-motorized users to cross the busway.
- Pedestrian phases can be provided every cycle or only when actuated.
- Pedestrian compliance with signals, particularly pedestrian actuated signals, is thought to be very low.

- Painted crosswalks at uncontrolled crossings may convey to pedestrians that they have the right of way.
- Pedestrian countdown signals are used in the Euclid Corridor.

Bus and Vehicle Control

- Some agencies used standard traffic signal indications along the busways while others used light rail transit signal indications.
- Closely spaced intersections may be problematic, as drivers may not see the busway intersection because they are focused downstream.
- Some agencies that used standard traffic signal indications reported problems with driver confusion and installed louvers and similar countermeasures to block the motorists' view of the bus signal.

OPERATIONAL PRACTICES

Unauthorized Entry to Busway

In addition to traffic control devices, some agencies use operational practices to deter unauthorized entry to the busways at intersections. In Pittsburgh, a supervisor is on the busway at all hours. Similarly, in Los Angeles, the agency plans on having a police car enter the busway on a regular basis and conduct a line sweep once the system is in operation. Ottawa has an extensive camera system that is monitored by the transit police.

Emergency Vehicle Service Treatment

Another operational consideration is the accommodation of emergency vehicles at at-grade busway intersections. Some agencies employ pre-emption while others give the emergency vehicles priority but no pre-emption capabilities. Systems that use pre-emption will have an impact on busway capacity by increasing delay at the intersection and an impact on safety by reducing the clearance interval for pedestrians.

TCRP Report 90 (1) concluded that emergency vehicles, police cars, free equipment, ambulances, and tour buses should be allowed to use bus lanes and bus streets. Emergency vehicles are generally allowed on busways. The emergency vehicles then use the intersections to enter and exit the busway. They may pose a safety problem at intersections if they are not expected by other users at the intersection. Some of the agencies surveyed reported problems with too many emergency vehicles using the system. No problems were reported at intersections from their use of the busway.

Signal Operation — Phasing

There are many possible movements that need to be accommodated at at-grade intersections of busways including bus movements, pedestrian movements, bicycle movements, vehicle turning movements on the major and minor roadway, and vehicle through movements on the major and minor roadway. The appropriate accommodation of those movements is largely dependent on the design of the intersection, the volume of the movements, and which movements are allowed.

TCRP Report 17 recommended that a lagging left turn movement should be used at intersections with LRT operations on the median if the LRV pre-empted the signal *(2)*. Part of the South Miami-Dade busway is a median busway; however leading left turns are used at the intersections.

In order to accommodate bus, vehicle and pedestrian movements at the intersection, South Miami-Dade and Los Angeles had to increase the number of signal phases. In Miami, the busway is treated as a special phase. The phase is skipped if there is no demand from the busway.

San Francisco Bay Area

An exclusive busway is proposed for the Telegraph – International Blvd. corridor between Berkeley, Oakland, and San Leandro in the San Francisco Bay Area. At this stage only 15% of the actual route design has been completed, though the basic philosophy for intersection operation has been determined — buses will make left turns from the right hand side of the busway using protected signal phases.

Los Angeles

In the soon-to–be-opened busway in Los Angeles, the signal system at the intersection will allow for five phases: mainline through, mainline left turns, minor street through, minor street left turns, and an exclusive busway cycle. The plan is for buses to proceed through the intersections only during the fifth phase of the cycle. The bus officials are concerned that left-turning traffic might violate the left turn signal during the parallel green movement. Since buses will not proceed through the intersection during the parallel green movement, the impact on safety of these left turn signal violators will be reduced.

An entirely new traffic signal control system is being installed in the corridor in conjunction with the start of the busway operations. If the buses average between 30 and 45 m.p.h. as they proceed along the busway, planners estimate the buses will clear most signalized intersections without stopping during the 20-second fifth phase of the traffic control systems. If passenger activity is particularly heavy at the stations, they may fall out of the planned sequencing. There will be no special treatment provided to buses such as green extensions, red truncations, or preemption as they travel on the busway.

It should be noted that the capacity of the intersections will be reduced with the five phase cycle instead of a four phase cycle. Vehicles and pedestrians will incur additional delay. The buses that do not stay in progression along the busways will have to wait through an entire signal.

Signal Operations — Cycle Length

Cycle length can have an effect on safety and level of service at an intersection. As discussed previously, at-grade intersections with busways may have many different movements to accommodate. In order to provide a phase for all of the various moments, longer cycle lengths are employed. Longer cycle length increases the delay of pedestrian and vehicles at the intersection. Additionally, longer cycle lengths can be a detriment to pedestrian safety. Pedestrians will have to wait longer for the phase. This increases the chance that pedestrians will cross during the DON'T WALK phase. Vehicles may also be more likely to violate the signal; however, the relationship between cycle length and signal violations has not been confirmed.

Busway Priority

Ottawa

In Ottawa, there are three signalized intersections with the busway. At the Lebreton Station intersection, the intersection operates in fixed time operation during the peak period and actuated during the off-peak period. During the off-peak period, the default green is for the highway. The Iris St. intersection is actuated at all times of the day. However, the detectors are far enough upstream that the buses usually receive a green signal by the time they reach the intersection. Once the first bus or group of buses passes through the intersection and the signal cycles back to green for Iris St. traffic, minimum green times for Iris St. must be maintained. Therefore, if a second bus arrives during this minim green time period for Iris St., it will be stopped at a red light until the minimum green times have finished.

Orlando

According to a report by the National Bus Rapid Transit Institute, the Lynx LYMMO system has exclusive bus phases actuated by the approaching buses at 11 of the intersections along the system *(3)*. Bus-only phases are about ten seconds in length and available only at the end of a concurrent auto phase or the beginning of an opposing phase.

During the interview with the bus agency, the representative stated that three intersections have signal priority with an exclusive phase for the bus, nine have an exclusive phase on-demand but not priority, and three operate with a light rail transit signal indication simultaneous to the phase for the traffic on the parallel traffic lane.

Hartford

When built, the Hartford system will employ a bus priority system that will extend or advance the green indication where signals are located adjacent to parallel streets. Where the busway parallels Amtrak, busway signals will be interconnected with the existing railroad protection warning system (crossing gates and flashers). There would be absolute priority for trains (as at present), and buses would receive a green indication when trains pass through the intersections. When there are buses but no trains, buses would receive a green indication at the planned time in the signal cycle.

Los Angeles

The soon-to-be-opened busway in Los Angeles will not provide special treatment to buses such as green extensions, red truncations, or preemption as they travel on the busway.

Denver

Although there is no signal priority for buses along the Denver transit mall, the cycle length and distance between intersections helps to progress the buses. The Denver transit mall uses a 75 second cycle length that coincides with the intervals of time it takes a bus to drive the distance of the block and the time for station stops. According to the transit agency, it takes each bus 25 seconds to go from one block to another (each block is 346 feet long). Each bus also stops at near side stops in every block located 16 feet from the intersection. Because of the free fare, low floors, and three boarding/alighting doors in the system, the bus averages 12.5 seconds at each stop. Hence, to cover two blocks takes 75 seconds (25 + 25+ 12.5 + 12.5). This allows the buses to travel along the entire corridor without typically stopping for a red signal indication.

Eugene

Signal preemption is not permitted in Oregon. The Eugene EmX system will use Traffic Signal Priority Indicator (TSPI) devices at signalized intersections. However, those surveyed in Portland noted that priority has limited value in congested urban areas, particularly in the downtown area due to heavy pedestrian flows.

Portland

Although not a busway, the Portland light rail system has 106 intersections controlled by traffic signals without gates. At these intersections, the oncoming train pre-empts the traffic signal system for the intersection. This stops all left turns and traffic intending to go straight through the intersection well in advance of the arrival of the train.

Prohibition of Movements

For parallel facilities such as some portions of the South Miami-Dade system, right turns on red are prohibited. In order to facility this, long dedicated right turn lanes with right turn arrow signal indications were added to southbound US 1. During the period that buses cross east-west intersecting roadways, the south-to-west right turn movements from US 1 are prohibited. Miami uses a static sign and red arrow indications on a separate signal head to communicate this message to the motorists. Northbound left turns from US 1 are also prohibited across the busway in the South Miami-Dade system.

In Vancouver, in order to safely accommodate U-turns from the main roadway, right turns on red are prohibited from the minor roadway. The median busway replaced a two-way left turn lane along No. 3 Road. Businesses were concerned that the busway limited the access of vehicles to the area. In order to increase access, U-turns were allowed from the main roadway across the busway during a protected left turn and U-turn phase. However, this U-turn movement resulted in conflicts with right turning vehicles from the minor street. The prohibition of right turns on red was implemented to eliminate these conflicts.

Influence on Surrounding Road Network

Busway intersections may have an effect on the surrounding road network, particularly if there are closely spaced intersections. Of the agencies surveyed, Miami-Dade, Los Angeles, and Ottawa all have closely spaced intersections. Because of the additional movements at busway intersections, longer cycle lengths are needed. This could affect coordination with the surrounding grid.

Queue Buildup

In Vancouver, many of the left turns at at-grade intersections have been prohibited, forcing private vehicles to make downstream U-turns. The conflict between U-turning or right turning vehicles and buses sometimes results in queue build-up and occasional blocking of bus movements. This is illustrated in Figure 3-1. Additionally, the bus agency noted that lack of signal progression in Richmond is a problem, and the bus agency stated a need to consider the downtown environments of Richmond and Vancouver in terms of the entire road network, not just as individual travel corridors.

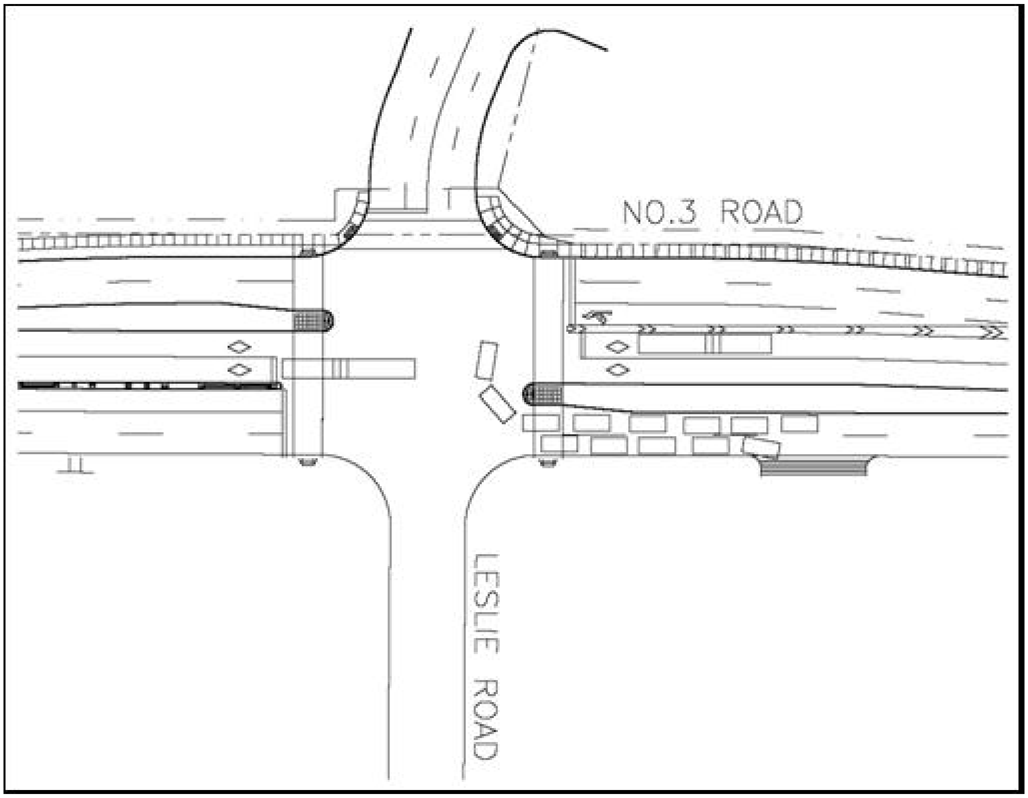


Figure 3-1: Illustration of Queue Back-up Over Busway in Vancouver at the Intersection of No. 3 Road and Leslie Road

TCRP Report 69 reports that the Edmonton Transit System had a similar concern with vehicles queuing over a light rail crossing *(4)*. A motor vehicle queuing monitor system was installed at a LRT crossing near a signalized intersection to prevent the queue from backing up onto the LRT crossing. When loop detectors buried in the pavement detect a queue is beginning to form, yellow beacons begin flashing next to a “Do Not Block Crossing” sign. The system also alters the timing and sequence of downstream traffic to allow for better traffic flow through the LRT crossing. The system is activated whether or not a light rail vehicle is approaching.

Ottawa

According to the Ottawa bus agency, overall there have been virtually no negative impacts on the surrounding roadway network. Busway intersections are incorporated into the roadway grid like any other intersection. Occasionally, there are problems with queues from adjacent intersections blocking the busway intersections. One countermeasure to this problem is to enforce the vehicle code that prohibit vehicles from entering an intersection unless they expect to clear the cross street before their signal turns red.

At one intersection in Ottawa, Iris St., the priority given to the busway is considered a traffic calming measure. The area suffers from “cut-through” traffic. The delay at the intersection caused by the priority given to the bus may deter that traffic.

Orlando

In Orlando, approaching buses can activate the signal. All time for activation of a bus-only phase is taken from the time allotted to the minor cross-street phases so progression on the major street is not disrupted.

The construction of the dedicated busway did reduce some capacity in the grid because it took right-of-way that could be used for all purpose lanes. However, the system has removed 4,200 vehicle trips from the downtown network. Queuing and queue spillover has not been a problem.

South Miami-Dade

When asked what impact, if any, the busway had on the surrounding roadway network, the bus agency and the highway agency provided different responses. Representatives of the Miami-Dade Bus agency believe that the impact has been positive, citing the conversion of vehicle trips on US 1 to transit trips. In addition, the Miami-Dade Transit buses have been removed from the general traffic flow on US 1, thereby producing fewer delays to traffic caused by buses stopping to pick up or drop off passengers.

Representatives from the Florida Department of Transportation noted that, although they are very supportive of the busway, the delays experienced by the traffic movements at the various intersections of US 1 and the busway have generally been degraded. The phasing of turning movements were adjusted to accommodate traffic moving through the wider intersection which now encompasses the busway and the right of way between US 1 and the busway. Longer phases are provided for turn movements and cross street movements which reduces the available time for through movements on US 1. Additionally, the elimination of right turn on red from US 1 reduces capacity for this movement.

Los Angeles

Although the system has not opened for operation, there is concern among traffic engineers in Los Angeles that the capacity of the intersections along the Metro Orange Line will be decreased due to the extra time needed to accommodate the exclusive bus phase. This may be offset by new ridership that may replace some vehicle trips on parallel routes with bus trips.

Denver

Representatives from both the bus agency and the highway agency in Denver agree that overall, the transit mall has benefited the surrounding road network by replacing single vehicle trips with transit trips. There haven't been any problems with spillovers or queuing of intersections.

Summary of Operational Practices

Unauthorized Entry to Busway

- Limited operational practices are used to deter unauthorized entry to busway.
- Line sweeps and monitored camera systems are employed.

Emergency Vehicle Service Treatment

- Emergency vehicles use the busways in most systems.

- Some agencies employ pre-emption while others only give the emergency vehicles a certain level of priority.
- No specific problems were reported at intersections from the use of the busway by emergency vehicles.

Signal Operation – Phasing

- Median busways usually increase the number of phases required at intersections.
- The appropriate phasing is dependent on the design of the intersection, the volume of the movements, and what movements will be permitted.
- Actuation can reduce the number of phases needed when demand for some of the movements is not present, including the busway.
- Concerns that left turning vehicles will violate turn prohibitions if the parallel movement has a green ball have prompted Los Angeles to use a five-phase signal with a separate phase for buses.

Signal Operations — Cycle Length

- The cycle length usually has to be lengthened to accommodate the extra movements at busway crossings, particularly for median busways.

Busway Priority

- Actuation can be used to extend or advance the green indication for buses.
- Upstream actuation can improve bus priority.
- Some agencies do not provide any special priority for buses but rely on the progression of the bus along the route to stay in coordination with the signals.
- Signal priority may have limited benefits in congested urban areas.

Prohibition of Movements

- Prohibition of right turn on red is necessary on roadways that run parallel to busways during the busway phase.
- For median busways, it may be necessary to prohibit right turns on red from the minor roadway if there is a large u-turn volume from the main roadway across the busway.
- Motorist compliance with right turn on red is problematic.
- Prohibition of left turns from parallel facilities across the busway may also be necessary.

Influence on Surrounding Road Network

- Traffic conditions and congestion at busway intersections may have an effect on the surrounding road network and progression, particularly if there are closely spaced intersections.
- Queuing across the busway should be monitored.
- Some treatments that may be necessary for the safe and efficient operation of the busway (i.e., prohibition of left or right turns, extra traffic signal phases, etc.) will decrease the capacity of the intersection and increase overall delay for motorists and pedestrians.

GEOMETRIC AND FUNCTIONAL DESIGN

Geometric and functional design issues include the general layout of the intersection or crossing (e.g. approach angles and sight distance), and features that are used to physically restrict or discourage motorists, pedestrians, or bicyclists from entering, or crossing the busway, (e.g. curbs, tight corner radii, barriers, rumble strips, fencing, etc.)

Unauthorized Entry to Busway

Motor Vehicles

In addition to traffic control devices and operational practices, geometric design can be used to deter unauthorized entry to busways.

At several fixed guideways in Europe and Australia, the bus tires run along narrow concrete running surfaces at the outside edges of the guideway, with a continuous gap in the center. Passenger vehicles typically have narrower wheel spacing and motorists would not be able to run their vehicles along the guideway.

At some locations along the O-bahn guided busway in Adelaide, South Australia, raised objects are placed in the middle of the busway. The devices are built low enough to allow the buses to pass safely, but high enough to damage the undercarriage of most passenger vehicles. While this is an effective deterrent, it should probably be avoided in North America, where it might increase the potential for lawsuits.

At minor intersections of busways that run down the median of existing surface arterials, continuous curbing can be used through the intersections, effectively severing the cross street and allowing only right turns into and out of the minor street. This is used in South America and other areas. This treatment is proposed on the I-80 Corridor Busway in the San Francisco Bay Area. This treatment is quite similar to typical access management techniques that are frequently used on urban thoroughfares throughout the United States.

Minor cross streets can also be terminated at busways on exclusive rights-of-way. Most rail rights-of-way already have limited crossings, and any rail rights-of-way that are converted to busways would be good candidates for this treatment. The forthcoming Orange Line project in Los Angeles is a good example of a rail line that is being converted to an exclusive busway where most or all of the existing minor side streets will remain closed.

Concrete barriers can be used to prevent motor vehicles from entering the busway. The proposed Hartford to New Britain Busway is planned with “Jersey” barriers that will help prevent motorists from entering the busway.

Incorrectly turning into the transitway is envisioned as the primary source of unauthorized entry in Eugene. To account for this, the entry ways have been designed to be very narrow, making incorrect entry on a turn movement very difficult.

Pedestrians

At side-aligned locations, many agencies have installed sidewalks to discourage pedestrians from using the busway as a walkway. Several transit systems use fencing or concrete barriers to encourage pedestrians to cross at intersection by physically restricting pedestrians from entering or crossing busways at mid-block or other undesirable locations. In other locations like the #98 B-Line in Vancouver, there are no barriers, and pedestrians have been observed crossing the median busway mid-block and walking along the median busway to transfer between routes. Examples of locations where barriers are used or proposed include:

- The proposed barriers on the Hartford — New Britain Busway will help keep pedestrians from entering or crossing the busway.
- In Ottawa, fencing is sometimes used along the median of the busway to prevent pedestrians from crossing the busway except at designated crosswalks.
- In Pittsburgh, concrete “Jersey” barriers and 42-inch handrail barriers have been installed at stations in order to keep pedestrians from crossing at unsafe locations.

Like vehicle drivers, pedestrians respond to pavement texture variations. In areas where the lines between the busway and pedestrian ways are not well defined, a change in pavement texture can help highlight the busway area. In contrast to this, on the 16th Street Transit/Pedestrian Mall in Denver, there are no discernable barriers or texture changes between the bus lanes and the rest of the pedestrian mall space. Even with the lack of separation, the number of incidents involving pedestrians has been minimal, primarily due to the slow bus travel speeds.

Approach Angles

As with any traditional intersection, complex busway intersection geometry can cause confusion to motorists, bicyclists, and pedestrians. According to the American Association of State Highway and Transportation Officials (AASHTO), “for safety and economy, intersecting roads should generally meet at or nearly at right angles.” AASHTO also recommends that when an acute angle of intersection exists, the road should be realigned so that the angle of intersection is closer to 90° *(5)*. The advantages of right angle crossings include a reduced conflict area, better general sight lines between buses and other users, and better driver and pedestrian expectation.

While most busway/roadway intersections are approximately 90°, there are several examples of locations with other angles. Some examples of skewed busway intersections include:

- Vancouver, BC - #98 B-Line in median of No. 3 Road
  - At Cambie Road – No. 3 Road (with the busway) is curved at the crossing of Cambie Road; the skew angle varies from about 62° to 77°.
  - At Capstain Way – On the west side of the busway on No. 3 Road, the skew angle is 60° (it is 90° on the east side).
  - At Leslie Road – On the west side of the busway on No. 3 Road, the approaching skew angle on Leslie Road is about 66°, although the road straightens to 90° right at the intersection.
- Ottawa Transitway
  - Waller Street Transitway at Laurier Avenue – Skew angle is about 81°.
  - Southwest Transitway– Skew angle of one intersection is about 82°.
- Los Angeles Orange Line – this busway is within an abandoned railroad right-of-way, so the busway is in an exclusive right-of-way. However, at many locations the crossing is very close to other intersections.
  - At the crossing of Winnetka Avenue, the busway has a skew angle of about 68°.

- At the crossing of Victory Blvd., the busway is in an exclusive right-of-way but adjacent to Topham Street – the Skew angle is about 52°.
- At the crossings of Corbin Avenue and Tampa Avenue, the busway is in an exclusive right-of-way and adjacent to Topham Street – the skew angle is about 68°.
- At the crossing of Woodman Avenue, the busway has a skew angle of about 63°.
- At the crossing of Oxnard Street, the busway has a skew angle of about 40°.
- At the crossing of Ethel Avenue, the busway has a skew angle of about 63°.
- At the crossing of westbound Chandler Avenue, the busway has a skew angle of about 30°.

The South Miami-Dade Busway runs parallel to US Highway 1 and both facilities run primarily in a south-southwest to north-northeast direction but the typical road grid in the area is generally north-south and east-west. As a result, out of the 19 intersections of the busway with surface streets, 10 intersections have a skew angle of approximately 64°. At 6 of these intersections, the busway is less than 100 feet from US Highway 1, which also has the same skew angle with the cross streets. Miami-Dade Transit and the Florida Department of Transportation have been dealing with a significant crash problem at many of these intersections. One of the primary causes of this problem has been drivers violating the "no turn on red" restrictions and turning across the busway without stopping. Due to the skew, these right turn movements take place on a corner with a flat, 115° angle; this allows higher turning speeds, possibly exacerbating the problem.

It is important to note that these measurements are based on the plans provided by the agency.

Channelization

Channelization issues are similar to those discussed in the unauthorized entry to busways section above. When busways are located within existing street rights-of-way, channelizing features such as curbs, medians, and islands are often used between the busway and normal motor vehicle lanes.

Mid-block Channelization of Vehicles

Raised curbs, medians, and islands are a common mid-block treatment for both side-aligned and median busways. The following agencies use curbs and medians at mid-block locations:

- Lynx Lymmo, Orlando – this busway includes mid-block channelization using wide curbs that act as narrow median separators, and wider median islands with room for plantings or street furniture.
- The proposed Euclid Avenue BRT line in Cleveland is proposed to have a continuous median island to channelize all vehicles to the appropriate side of the roadway.

On slower-speed urban busways, geometric treatments with less restriction are often used for mid-block channelization. For example, rumble strips provide more restriction than simple pavement markings but less restriction than curbs or medians. Rumble strips can be either the ground-in type or constructed using continuous strips of raised pavement markers (either reflective or non-reflective). One advantage of rumble strips over curbs or medians is that they allow buses and cars to change lanes in the event the lane they are using is blocked. Examples of locations that have used rumble strips for mid-block channelization are as follows:

- Lynx Lymmo, Orlando - between intersections the Lymmo system uses rumble strips formed with ceramic raised pavement markers in addition to the curbs and medians discussed above.
- Euclid Avenue BRT – Cleveland – A one-foot wide rumble strip will be placed between the exclusive transit lanes and the normal travel lanes.

A few high-speed busways, typically Bus Rapid Transit lines, have concrete barriers that channelize traffic at mid-block locations. An example is the “Jersey” barrier planned for the Hartford to New Britain Busway. It will channelize both motor vehicle and busway traffic into the appropriate lanes.

Both barriers and curbs can be a hazard if struck by errant vehicles. Curbs can cause vaulting when impacted at an improper angle. Drivers tend to “shy” away from barriers and other vertical objects, effectively narrowing the usable width of the roadway. In addition, if barriers are struck at high angles, serious crashes can result.

Intersection Channelization of Vehicles

At intersections, in order to maintain bus priority and safety, channelization is often even more important to provide buses an exclusive lane. The channelization does more than prevent vehicles from entering the busway; it directs bus drivers and motorists into the appropriate lanes and allows buses to take advantage of special signals for buses. In addition, where buses make right turns, a channelized “slip lane” allows bus drivers to traverse the intersection without using the traffic signals at all, potentially reducing the number of signal phases, which provides a better level of services for all users.

Several bus agencies including Vancouver have reported problems with motorists using side-aligned busways when making right turns. At intersections, vehicles can be channelized using the same basic methods including rumble strips, curbs, medians, islands, and barriers. However, on corners, barriers are hard to construct and the likelihood of a high-angle crash is increased, so this is not a good method. Rumble strips are less effective on curves since some drivers will cut corners. Curbs are the best solution for channelization at intersections.

The Lynx Lymmo system in Orlando has curbs or islands that are used as channelization between bus traffic and other vehicular traffic. There are five locations on the Lymmo route where the bus makes a right turn at intersections, sometimes in a contra-flow direction to traffic on one or both adjacent streets. At four of these locations, curbs or islands are used as channelization (locations include South Street at Orange Avenue, Orange Avenue at Church Street, Magnolia Avenue at South Street, and Livingston Street at Garland Avenue). At a single location on the Lymmo system (Hughey Avenue at Alexander Street), the intersection channelization is handled with just rumble strips. This is a lower-volume intersection so the lack of physical separation is not a major concern.

At locations where buses make left turns, channelization is used to supplement traffic signals and other traffic control devices in providing safe intersections between bus traffic and other motor vehicle traffic. For example, the Lynx Lymmo system uses curbs islands, and rumble strips for channelization at several bus left turn locations including Hughey Avenue at Livingston Street, Garland Avenue at Amelia Street, and Magnolia Avenue at Livingston Street.

At locations where gates may be used to control traffic at busway crossings, channelization in the form of center curbs or medians is helpful to keep drivers from going around the gates.

This treatment is currently used at light rail lines in many locations. This may be applicable where gates are proposed for the future Hartford – New Britain Busway and on the South Miami-Dade Busway.

Mid-block Channelization of Pedestrians

For pedestrians at mid-block locations, channelization is about the same as the treatments used to prevent unauthorized entry as discussed at the beginning of this geometric design section. These fences and barriers act to channelize pedestrians to designated crossing locations.

Intersection Channelization of Pedestrians

As described above, fences and barriers are used to channelize pedestrians to the designated crossing locations. In addition, at the Pittsburgh busways, "Z" channelization is used at station locations where pedestrian movements intersect with the busway. The Z channelization uses an angled walkway in the median to discourage one-step crossings and encourage pedestrians to look toward the direction of the next potential oncoming bus.

Sight Distance

Sight distance at intersections between busways and streets should be calculated using the standard methods used for calculating sight distance. Guidelines and formulae for calculating intersection sight distance and stopping sight distance are provided by the AASHTO *(5)*. AASHTO recommends that at-grade crossings are designed so an approaching motorist is able to see the vehicle, react, and stop prior to the crossing *(5)*. Sight distance is important for vehicles and pedestrians. Land use, travel speeds, traffic control, and other factors affect the sight distance. For busways, there are a few differences that should be considered. First, since the busway vehicles are typically standardized to some degree, it may be appropriate to adjust the driver eye height to the actual eye height of the bus instead of using the standard value. Second, since there are only a few drivers using the busways, policy directives can be used to control travel speeds throughout the busway and speeds could easily be reduced at locations where sight distance or other issues are a particular concern. On the Los Angeles Orange Line, sound walls have been built to insulate adjacent neighborhoods from the sounds of the buses that will operate into the evening hours. These sound walls can affect sight distance and the design must be carefully considered or mitigating measures must be taken.

In Vancouver, there is a sight distance restriction for buses using a bus-only ramp to a bridge. Due to the elevation change, bus drivers can not see ahead of them as well as necessary. A loop detector was added to detect buses and activate a flasher on a sign that says "Yield to Buses When Flashing".

Summary of Geometric and Functional Design

Unauthorized Entry to Busway

- Design elements employed outside of the United States and Canada include raised objects and narrow guideways for buses. These treatments may not be applicable in the United States.
- Minor cross streets can be terminated or through movements severed through the use of continuous curbing along the busways on exclusive rights-of-way.
- Narrow entryways can be employed.

- At side-aligned locations, many agencies have installed sidewalks, fencing, or concrete barriers to discourage pedestrians from using the busway as a walkway or crossing at midblock.
- Pavement textures can be used to differentiate busways to pedestrians.

Approach Angles

- AASHTO recommends roads should be aligned at intersections at angles close to 90°.
- Several skewed busways exist in the U.S. and Canada including skew angles as small as 30°.
- Skewed intersections may experience higher rates of driver violation of right turn on red prohibitions.

Intersection Channelization of Vehicles

- At intersections, vehicles can be channelized using rumble strips, curbs, medians, islands, and barriers. Traffic volume may determine the best method.
- Barriers can create a safety hazard at intersections.
- Curbs are the best solution for channelization at intersections.
- At locations where buses make left turns, channelization is used to supplement traffic signals and other traffic control devices in providing safe intersections between bus traffic and other motor vehicle traffic.

Intersection Channelization of Pedestrians

- Fences, barriers, and "Z" channelization are used to channelize pedestrians to the designated crossing locations.

Sight Distance

- Sight distance should be calculated using the standard methods in AASHTO.
- For busways, there are a few differences that should be considered including the actual eye height of the bus and that the busway has a limited, controlled population of drivers,

PUBLIC EDUCATION AND AWARENESS

The surveyed agencies were asked if any publication education or awareness efforts were undertaken to educate the public about the operation of at-grade intersections with busways. One agency commented, "If you design it correctly, you don't need to educate people." However, other agencies used public education as a mechanism to increase safety at these intersections. Most agencies include some public information on their websites.

Vancouver

During the planning phase, many businesses were concerned about the reduction in access that would be caused by the elimination of dual left turn lanes at the intersections. The bus agency, TransLink, and the City of Richmond conducted one-on-one meetings with property owners, block meetings, and public open houses to familiarize the public with the intended configuration and to answer questions.

The Vancouver bus agency conducted an extensive marketing campaign when they installed a new U-turn configuration at the intersections. The revised intersection configuration was necessary to mitigate safety problems at the intersections. Because the new configuration was unconventional, a "how-to" brochure was distributed to the public. It was also necessary to ease the fears of the local business community. They were concerned that the new configuration may reduce access to their businesses.

Ottawa

Ottawa did not employ a public information and education program prior to the opening of the busway. They reasoned that since the intersections were designed to be similar to standard intersections, no special education of motorists or pedestrians was required.

Portland

Although not at a busway intersection, Portland experienced quite a few crashes at their at-grade light rail crossings. In response to this they developed a video documenting the danger at these intersections. The video is used in area schools as part of the driver education program.

Denver

The Denver Transit System developed media announcements that were used before new service started along their routes. They also employ public service announcements for special events that may be affected by the system.

The Denver transit mall distributed announcements through the media before the mall was opened. The Downtown Improvement District helped to educate the many businesses operating in and near the mall. Brochures were developed for passengers that would need to transfer to the mall buses to complete their trips. Since the mall opened in 1982, there has not been a need to continue with public education programs.

South Miami-Dade

Prior to the implementation of the busway system, coverage of public meetings on the busway was televised. These meetings were held for six months prior to the opening of the busway and six months after. At the public meetings, a four-minute video was used to illustrate how the busway would look and operate. In addition to televised coverage of the public meetings, they aired televised shots of the busway on the cable station.

Los Angeles

The LAMTA is developing a safety video that it plans to take and show in schools, colleges, community meetings, and at regional events. Their website also has a section to advise the public of the status of the project and what it will provide for passengers. The agency expects to work extensively with local and regional media outlets to provide other channels of information to the communities surrounding the busway.

Pittsburgh

The bus agency in Pittsburgh, PAT, holds annual meetings with local schools and universities that are served by the busways. At these meetings, the nature of the services available is discussed and safe practices are also covered. There are other meetings held with community groups from time to time as well. PAT also places brochures on its buses that provide riders with safety tips in terms of accessing buses at the busways. Messages of this nature are also placed on PAT's website under "Rider Alerts".

Summary of Public Education and Awareness

- Many agencies used public education as a mechanism to increase safety at these intersections including public information on their websites.
- Public education includes public meetings, brochures, television coverage, videos, and public service announcements.
- Most public education programs did not continue in any substantial way after the opening of the busway.

ENFORCEMENT

Enforcement can be used at busway intersections to affect safety by preventing unauthorized entry and ensuring compliance with traffic control devices,

Unauthorized Entry to Busways

As discussed in the operational procedures section, Los Angeles and Ottawa both use enforcement practices to control unauthorized entry to busways. In Los Angeles, the transit system plans on having a police car enter the busway on a regular basis and conduct a line sweep once the system is in operation. Ottawa has an extensive camera system that is monitored by the transit police.

Other than camera systems, none of the agencies surveyed used automated enforcement strategies to deter unauthorized entry.

Compliance with Traffic Control Devices

Enforcement of traffic control devices includes motorist, pedestrian, and bicyclist compliance of signals, signs, and pavement markings. Red light running cameras are widely used to enforce vehicle compliance with traffic signals. However, none of the agencies surveyed employed this enforcement tool. Only standard enforcement is used to enforce traffic control devices at these intersections.

Some agencies, particularly Pittsburgh, have reported problems with pedestrians walking down the busways. This is enforced with frequent patrols of the busway.

No agencies surveyed reported any special enforcement of pedestrian compliance to signals or any targeted enforcement of vehicle actions at intersections.

INSTITUTIONAL PRACTICES

Bus Operation Procedures

The operating procedures of buses on the approach and at the intersection with highways and pedestrian and bicycle paths can affect the safety of the intersection.

Ottawa

Ottawa experienced a safety problem at one intersection with heavy pedestrian volumes and high-speed bus operation. In response to this safety problem, bus operators are now trained to slow down at this intersection and to watch for pedestrians.

Ottawa has also experienced a safety problem with pedestrians crossing the busway illegally at various points. Bus operators are trained to watch out for these wayward pedestrians.

South Miami-Dade

In the South Miami-Dade system, bus operators are trained to slow down to 15 m.p.h. as they approach intersections, even if they have the green signal indication. This operating procedure was put into place two years ago in response to a crash problem at intersections.

Portland

The City of Portland uses wayside horns at their light rail at-grade crossings. The volume of the horns was recently made louder to increase the warning that the light rail train is approaching for motorists, pedestrians, and bicyclists at the intersection.

Los Angeles

Although the system is not in operation yet, the bus agency is concerned that sight distance may be an issue for bus operators, particularly on sections of the busway equipped with a sound wall. These sound walls will limit a bus operator's ability to see vehicles approaching the busway from intersecting streets (and vice versa) until they are very near the intersections. As the bus agency develops its Standard Operating Procedures for the Busway, it will be making efforts to train bus operators to take even more care as they approach intersections where visibility of intersecting traffic is limited.

Pittsburgh

There have been some safety problems with pedestrians at stops along the three Pittsburgh busways. The maximum speed permitted on the busways is 50 m.p.h. To enhance safety, all buses are required to slow to 25 m.p.h. when approaching a station even if there are no buses at the station, and they are required to slow to 15 m.p.h. if there is another vehicle stopped at the station.

Far-Side versus Near-Side Bus Stops

Bus stops located at intersections can either be placed before the intersection (near-side) or after the intersection (far-side). The decision where to place these stops may be based on efficient system operations, concerns for safety, the available right-of-way, or the location of activity generators at the intersection.

Vancouver

In Vancouver, the busway route features a mixture of near-side and far-side stops. When surveyed, the agency noted that near-side stops are not at a disadvantage to far-side stops in the median busway because there is no right-turn traffic in front of the bus stopping in the nearside.

Ottawa

The busway in Ottawa mainly uses stations and stops located on the far-side of the intersection. This enables them to provide priority measures for the bus. At some of the stops, far-side stops were not possible due to space limitations.

Orlando

Bus stops in the Orlando system are generally located on the near-side of intersections. The imbedded coils for signal actuated are located in advance of the signal so buses are not sensed while at the station.

Hartford

The planned Hartford system would employ far-side "opposite" platform configurations. Pedestrians crossing between the two sides of the busway would cross behind stopped buses and have adequate sight lines to cross the through traffic on the intersection roadway.

South Miami-Dade

Most of the transit stations on the current busway are located at the far-side of intersections. For the extensions of the busway which will be opened for service by the end of 2006, the stops will be placed on the near-side of the intersections. The most prominent reason for designing stations on the near side of intersections in the future is to make the distance for passengers with disabilities as short as possible between exiting the bus and getting to the intersection, and to transfer to other buses. There are pullout bus bays at all station stops as well as shelters where passengers are picked up and dropped off. This allows other buses traveling in the same direction to pass a bus picking up or dropping off passengers if the passing buses are not stopping at that station.

Los Angeles

Bus stations are being positioned at the far side of intersections whenever possible to allow the bus to save running time by clearing the traffic signal prior to boarding and alighting passengers. The busway will widen at the station areas, allowing other buses to safely pass a stopped vehicle.

Eugene

Stations are located in the median. The transitway operator has endeavored to construct double sided stations along the BRT route. As such they are near-side in one direction and far-side in the other. The single-lane two way transitway splits to go around both sides of the station then reconnects at the other side, thus providing curbside pickup in both directions. The buses are equipped with doors on both sides of the vehicles.

Federal Transit Administration Safety Plans

Currently, busways are not required by the Federal Transit Administration (FTA) to have a system safety plan. However, a similar plan may be required by the states. The planned busway in the Euclid corridor in Cleveland has a system safety plan in place.

Safety Audits

Road safety audits (RSAs) are gaining popularity in the United States as a tool to evaluate existing or planned facilities and identify safety deficiencies. Third party safety audits may be a useful tool at at-grade busway intersections to increase the safety of the intersection. This was recommended by the bus agency in Vancouver. RSAs can be conducted at the design phase, during construction, or once the system is in place. Neither the literature review nor the survey of agencies found any bus or highway agencies that have used RSAs at at-grade busway intersections.

Summary of Institutional Practices

Bus Operation Procedures

- Driver training can be used at areas along the route with identified safety concerns, particularly related to pedestrians.
- Some bus operators are trained to slow down as they approach intersections out of concern for safety.
- Wayside horns can be employed on the approach to intersections.

Far-Side versus Near-Side Bus Stops

- Agencies employed both near-side and far-side stops.
- Concerns for the placement of stops often were related to bus priority or pedestrian safety.

Safety Audits

- Third party road safety audits may be a useful tool at at-grade busway intersections to increase the safety of the intersection.

INTERDISCIPLINARY PRACTICES

Coordination and Communication between Bus and Highway Agency

Surveyed agencies were asked if lack of communication between bus and highway agencies could result in reduced safety at at-grade busway intersections. Multiple agencies may be involved in the design and operation of the intersection. Some of the surveyed agencies responded that this is a problem in the design safety. There can be a lack of communication between the agencies that result in a safety problem.

Denver noted that lack of coordination with the bus agency is a safety issue. (Add material.) However, they also indicated that they had good coordination in the implementation of their transit mall.

Some agencies also provided examples of coordination between agencies that benefited safety at intersections. Vancouver has one agency with roadway engineers and bus planners. This increases coordination. Similarly, the Ottawa bus agency recently came under the purview of the City.

The Los Angeles system had benefits for both the highway agency and the bus agency. Grant funds secured by the bus agency are paying for the improvements to the traffic control system in the corridor which will also benefit highway users. Additionally, the additional of a separate bicycle facility will separate the bicyclists from the vehicle traffic for the majority of the corridor.

During the planning and implementation of Denver transit mall, there was excellent collaboration between the bus agency, the City of Denver, and the Colorado DOT. From 1979 to 1986, there was an interagency task force that met regularly to discuss all elements of the operations and design of the transit mall. In 2002, there was a reassessment of the transportation master plan for downtown Denver. All parties reaffirmed their commitment to making the mall the centerpiece of the traffic control system. Of particular note, the 75-second traffic light cycle was retained for the 16th Street Mall, and the rest of the traffic control system for downtown Denver was driven by this decision.

REPORTED SAFETY PERFORMANCE

Surveyed agencies were asked to comment on the overall safety performance of the at-grade intersections of their busway. The safety concerns and reported performance varied by agency. The responses of some agencies are detailed in the following section.

Vancouver

The Vancouver bus agency responded that many safety concerns were identified during the planning stages of their facility. Specifically related to the median busway, there were concerns about the safety of having bus stops in the median. The agency reported that good design ensured that this issue and others were effectively addressed and no post-implementation problems were observed. In order to accommodate the busway, the vehicle lanes were narrowed as part of a "street urbanization" program. The narrow lanes reduced vehicle speeds along the corridor. The agency reports a decrease in crashes on the corridor since the busway was put into place. In the first six months of operation, motor vehicle crashes rates on the section of road with the busway declined by 19% from 1999 to 2001. The decline is attributed to the elimination of the dual left turn lane and the restriction of left turns to signalized intersections *(1)*.

As discussed in the section on operations, Vancouver experienced problems with left turning vehicles interpreting the bus signal as their own. These vehicles turning during the busway indication resulted in 15 vehicle crashes in which the vehicle hit the right side of the bus. No fatalities were reported. The position of the bus signals to the left of the left turn signals was the likely cause of this problem. Louver screens were added to the signals to address this problem. The other bus accident involved a pedestrian.

Ottawa

The Ottawa bus agency responded that, in general, there are few conflicts and crash experience is minimal. The bus-only lanes have been found to be similar to the regular lanes in terms of safety. Some conflicts exist at the Mann Avenue pedestrian crossing where there is a combination of high pedestrian volumes, high bus volumes, and high speeds along the busway. Several crashes and many "near-misses" occurred at this location over the years. In 20 years of operation, there has only been one fatality at this location. It involved an impaired cyclist. In an effort to increase safety at this crossing, the painted crosswalk was removed so pedestrians would be clear that buses have the right-of-way. Bus drivers were also asked to be especially alert at this location.

In one incident, an errant pickup truck entered the busway and was involved in a crash with a bus. The pickup truck driver, realizing that they should not be on the busway, attempted to make a U-turn, and was struck by the bus. Signage at this location was changed to indicate that wayward motorists should continue along the busway to the next access ramp to exit.

Orlando

Orlando identified conflicts with driveways that cross the busway as a potential safety problem, although only a few crashes have ever occurred. This may largely be attributed to the bus operators' awareness that drivers may be confused at these locations.

Unauthorized use of the busway was also identified as a potential safety problem. To address this problem, additional signage was installed to warn vehicles not to enter the busway.

South Miami-Dade

A safety study was conducted in August 2001 in response to a number of crashes that occurred along the busway *(6)*. From February 1997 to November 2000, 67 crashes that involved buses were recorded at busway intersections. Seventy three percent of the recorded crashes resulted in injuries and two resulted in fatalities. There have been no reported crashes with pedestrian on the busway to date.

The study found that a greater likelihood (seven times) of crashes existed at busway intersections that were independent of other intersections. Most of these intersections were in the southern section of the busway where there is a distance of several hundred feet between the busway and US 1. The study also determined that crashes were seven times more likely when the advanced loop detectors, installed for signal priority, were enabled than when they were not. When the loop detectors were activated, buses were able to receive a green signal and continue along the busway at the corridor speed of 45 m.p.h.

At the intersections that were shared between the Busway and US 1 in the northern portions of the busway, a high number of crashes were the result of right turn on red violations.

The southern intersections, which were originally treated as separate intersections from US 1 due to the distance between the two, the predominant crash patterns involved east bound vehicles. These vehicles likely did not see the separate signal for the busway intersection and violated the signal. One possible cause of these signal violates is the lack of visual information (e.g., turn bays) at the busway crossing that would identify it as an intersection. In response to this safety concern, the southern intersections were coordinated with the US 1 intersection so that both signals displayed the same indication. Later, programmable signal heads were installed.

Signage along the busway was also a consideration of the study. When the report was completed, the location of existing crossway signs was more than 100 feet from the bus crossings. This placement was inconsistent with the MUTCD, which suggest placing crossway signs at intersections or as close as possible. Visibility of signs along the corridor was also a consideration. Vegetation was overgrown along areas of the busway, thereby restricting the visibility for some of the signs.

The study developed short term recommendations for safety improvements including:

- Modify loop detectors installed at near side bus stops,
- Modify the advanced loop operations for a bus approach speed of 15 m.p.h.,
- Remove overgrown vegetation, and
- Install additional busway Crossing Warning signs.

Medium term recommendations included:

- Install a textured road surface at isolated busway intersections,
- Install in-roadway amber-red lights, and
- Install a raised central island on side street approaches of isolated intersections.

Long term recommendations included:

- Install flashing signals, such as those used for moveable bridges and railroad crossings,
- Install automatic gates, and
- Install grade separated intersections.

Denver

According to the bus agency, while there haven't been any crashes with vehicles at intersections, there have been almost 40 collisions between buses and pedestrians since the transit mall opened in 1982. Six of those have been serious, including one fatality.

The transit mall has a large volume of pedestrians that use the busway; the daily volume is approximately 150,000 pedestrians. These large volumes of pedestrians combine with the large volume of relatively quiet hybrid-electric buses on the busway. There are no discernable barriers between the bus lanes and the pedestrian space. The buses operate on four-inch wide granite pavers. These are the same tiles that make up the entire mall floor however they are changed in direction for where the bus wheels normally operate. Buses usually travel along the mall at a speed less than 15 mph.

The most typical crash has been when buses brush pedestrians that are not alert to the bus that is quietly going past them. Another type of crash involves people who get their arms stuck in the closing bus door as the vehicle tries to stay on its 75-second cycle between traffic lights. City officials have considered doing something to provide more awareness of the presence of buses to pedestrians including putting tactile borders along the running ways of the bus, painting the running way in some fashion, or installing an inlay pattern on the curb just before the bus path. After the fatal crash, there was some talk of putting railings along the bus path, but railings would present challenges when snow needs to be cleared, and there was a fear that someone could actually be trapped between the bus and the railings. To date, no specific plan to reduce pedestrian crashes has been adopted.

Pittsburgh

The Port Authority of Allegheny County, also known as PAT, owns and operates three dedicated busways in the Pittsburgh, Pennsylvania region including the South Busway, the Martin Luther King East Busway, and the West Busway. With the exception of bus entry and exit points, there is only one at-grade intersection with highways. They have not experienced safety problems at this one intersection. The safety concerns on the busways involve pedestrians. There have been a number of collisions with pedestrians. Some of these happen when pedestrians cross midblock. Concrete Jersey barriers have been erected in the middle of the busway at the stations that channel pedestrians who need to cross the busway to the marked crossing areas. Forty-two inch handrail barriers have also been installed at the station stops that prevent passengers from walking in front of the bus by channeling those who are alighting from the bus to the rear of the bus. This prevents them from exiting the bus and walking across the front of the bus where their vision is blocked of any oncoming vehicle.

There are some stations that include pedestrian overpasses that allow passengers to cross the busway safely. These are built when the topography of the area makes it convenient for passengers from other bus routes on nearby roads to go to and from their buses to the appropriate side of the busway via the pedestrian bridge. However, relatively few busway passengers who are simply going from one side of the busway to the other use these pedestrian bridges.

Portland

Since 1986, the Portland light rail system has experienced 390 encounters between MAX trains and other users at the intersections controlled by traffic signals. Of the 390, 330 of the encounters were with vehicles, while 60 were with pedestrians.

The survey respondent noted that there is a need to balance noise concerns in a community with safety. The light rail vehicles were originally equipped with relatively quiet horns in order to minimize noise impacts on surrounding communities. Tri-Met has since modified all of their MAX vehicles to have horns that sound like a train, so there is more warning, and no mistaking that an unusually large and heavy vehicle is approaching.

At some intersections, Tri-Met has installed a flashing LED sign next to the traffic signal that warns that a light rail vehicle is approaching. These are used at intersections without gating. For vehicles that are moving parallel to the rail track and in a left turn pocket at a crossing intersection, there is a flashing LED next to the traffic signal that shows the front of a train, which is what a car would see if it went through the intersection too early and tried to make a left turn over the tracks. The same flashing icon is visible for vehicles that are running on streets parallel to the rail line waiting to make a right turn across the tracks. It is not normal for someone to look behind them when making a right turn from the far right lane, yet that is the direction from which the train would be coming. The flashing icon provides another warning to a vehicle driver who is executing such a move over the tracks. For traffic that is intending to go straight through the intersection, the flashing icon shows the side of a rail car, which is what a car would soon see if it attempted to go through the intersection too early.

Summary of Reported Safety Performance

The reported safety performance of some of the surveyed agencies is summarized in the following sections.

Vancouver

- Vehicle lanes in the busway corridor were narrowed and resulted in decreased speed.
- The elimination of dual lefts and restriction of some lefts resulted in a decrease in crashes.
- The addition of louver screens reduced crashes resulting from left turning vehicles interpreting the bus signal as their own.

Ottawa

- A combination of high pedestrian volumes, high bus volumes, and high speeds along the busway generated pedestrian safety concerns at one crossing.
- The painted crosswalk was removed at this crossing so pedestrians would be clear that buses have the right-of-way.

Orlando

- Conflicts with driveways are a potential safety problem.
- Unauthorized entry is a potential safety problem.

South Miami-Dade

- Crashes were more likely at busway intersections that were independent of the closely spaced US 1 intersection.
- Violation of right turn on red prohibition caused a high number of crashes.
- Awareness of the busway intersection may have caused some safety problems.

Denver

- The relatively quiet operation of the buses and the lack of discernable boundaries between bus lanes and pedestrians space may produce conflicts.
- Typical crashes include buses brushing pedestrians and passengers getting their arms stuck in doors.

Pittsburgh

- The main safety concerns on the busways involve pedestrians crossing midblock.
- Few busway passengers use pedestrian bridges.

Portland

- Portland has taken two measures, a louder horn and LED signs, to provide additional warning to motorists and pedestrians that a train is coming.

CONCLUSIONS

This appendix documents the findings of Task 3 of TCRP Project D-11. It presents the state-of-practice on busways at-grade crossings, as it is applicable to the U.S. It was completed in May 2005. This appendix is based on the literature review, survey of findings, and knowledge of the project team. Various elements of traffic control devices, operational practices, geometric and functional design, public education and awareness, enforcement, institutional practices, and interdisciplinary practices are presented.

Based on this review, the project team identified some gaps in the available knowledge. One of the objectives of the site visits in Task 7 was to gain information to fill these gaps.

REFERENCES

1. Levinson, H., S. Zimmerman, J. Clinger, S. Rutherford, R.L. Smith, J. Cracknell, and R. Soberman. *TCRP Report 90*: *Bus Rapid Transit, Vol. 1: Case Studies in Bus Rapid Transit* and *Vol. 2: Implementation Guidelines*. Transportation Research Board of the National Academies, Washington, D.C., 2003.
2. Korve, Hans W. *TCRP Report 17: Integration of Light Rail Transit into City Streets.* Transportation Research Board, National Research Council, Washington, D.C., 1996.
3. Baltes, M.R., and D. Hinebaugh. *Lynx LYMMO Bus Rapid Transit Evaluation.* National Bus Rapid Transit Institute, Center for Urban Transportation Research, University of South Florida, 2003.
4. Korve, H.W., B.D. Ogden, J.T. Siques; D.M. Mansel, H.A. Richards, S. Gilbert, E. Boni, M. Butchko, J.C. Stutts, and R.G. Hughes. *TCRP Report 69: Light Rail Service: Pedestrian and Vehicle Safety,* Transportation Research Board, National Research Council, Washington, D.C., 2001.
5. American Association of State Highway and Transportation Officials, *A Policy on Geometric Design of Highways and Streets*, Washington, D.C. 2001.
6. DMJM+Harris and F.R. Aleman and Associates, "South Miami-Dade Busway Safety Study – Volume 1," August 2001.

APPENDIX C
CLEVELAND EUCLID AVENUE BUS RAPID TRANSIT

The Euclid Avenue Bus Rapid Transit (BRT) system, known as the Silver Line, is a planned BRT system as part of the Euclid Corridor Transportation Project in Cleveland, Ohio. Construction will start in the spring of 2006 and the service is scheduled to be fully operational by 2008 with portions in operation by 2007. The length of the corridor is 7.07 miles which extends along the Euclid Avenue from the Cleveland Public Square in downtown to the East Cleveland Stokes-Windermere Rapid Transit Station. The corridor will be comprised of a variety of different running way types including 4.37 miles of exclusive busway lanes which will serve as the subject of this case study.

The project team visited the Cleveland, Ohio area in late October 2005 to conduct the case study. The project team met with representatives of the City of Cleveland, Greater Cleveland Regional Transit Authority (GCRTA), Ohio Department of Transportation (ODOT), and two consultants to the project, Parsons and Wilbur Smith Associates. Case study participants included the following individuals:

- Michael J. Schipper, P.E., RTA
- Gary Thayer, RTA
- John Motl, Ohio DOT
- Ralph Trepal, P.E., Wilbur Smith Associates
- Vinod Dega, P.E., P.T.O.E., Wilbur Smith Associates
- Bill Crowley, P.E., Wilbur Smith Associates
- David E. Benjamin, Parsons

The planned service frequency is 5-minute headways during peak and base periods (weekdays and Saturdays) and 15-minute headways during off peak periods (weekday, evening and Sundays). The GCRTA plans to use 20 New Flyer hybrid-electric buses that are low-floor, articulated, and Americans with Disabilities Act (ADA) compliant. The buses have doors on both sides that allow for boarding and alighting from both sides of the bus. The vehicles are very quiet in electric mode. The sounding horn for the vehicle is still in development. These 60-foot long buses will service 23 stations along the exclusive busway configuration. The proposed busway speed limit is 35 MPH while the general purpose traffic speed limit will be 25 MPH.

DESIGN

General Design

Euclid Avenue is primarily a four-lane, undivided arterial street. A 70-foot curb-to-curb section is located within a 100-foot right-of-way through most of the project area. Major parallel roadways carry most of the traffic east of University Circle. The Euclid Avenue Corridor is shown in Figure C-1.

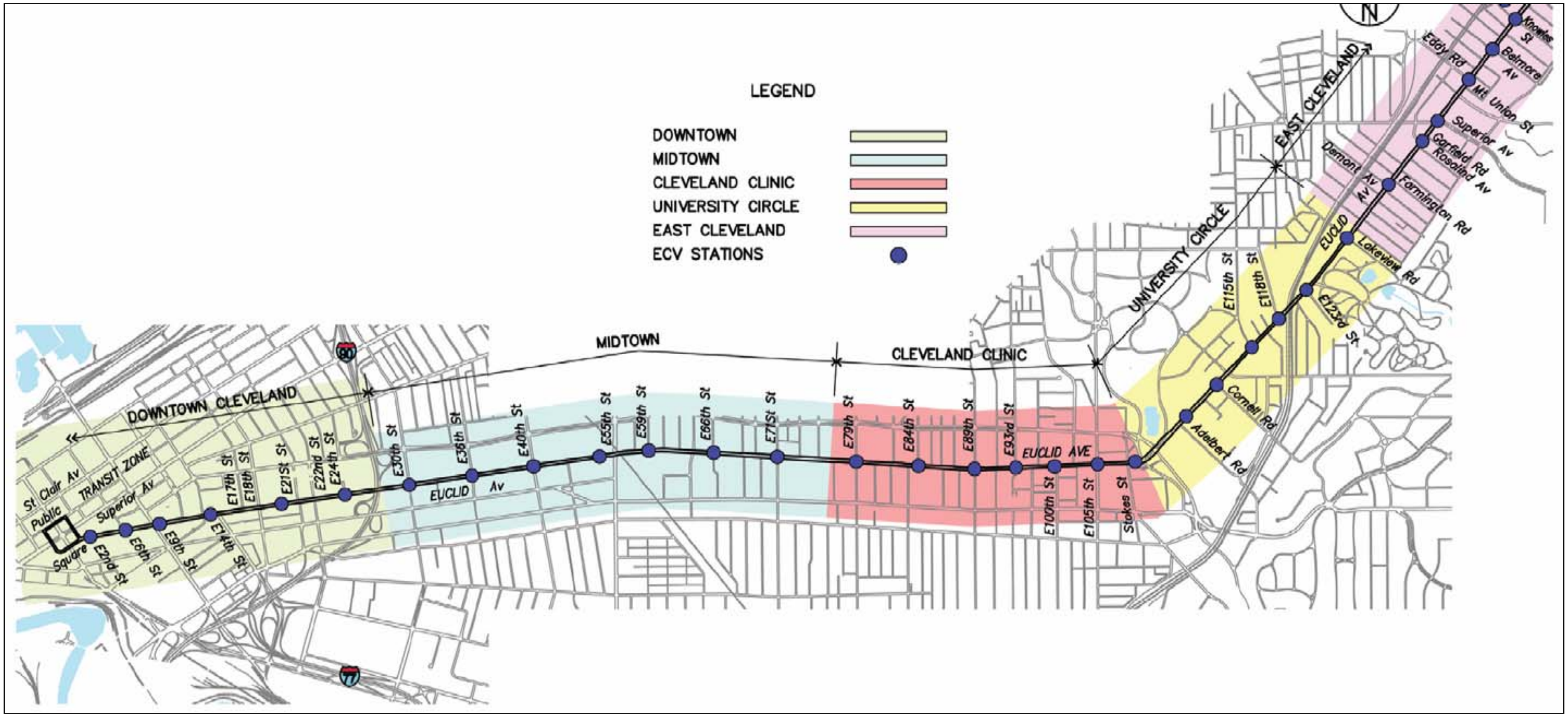


Figure C-1: Euclid Avenue Bus Rapid Transit Corridor
Source: The Greater Cleveland Transit Authority, Euclid Corridor Transportation Project website. http://euclidtransit.org/maps/default.asp. Extracted March 13, 2006

The corridor is divided into three sections, each with different elements and busway configurations. The first section is just over one mile long and runs between Public Square and East 17th Street. In this section, bus lanes will be flanked by a central landscaped median and separated from a single traffic lane each way by grooved rumble strips mid-block. Buses in both directions will board and alight passengers from a common station in the median of the road using left-side doors. Only Silver Line BRT buses will operate in this section, because of the left-side boardings. Figure C-2 shows the intersection of 6th Street and Euclid Avenue, which represents a typical intersection for this section.

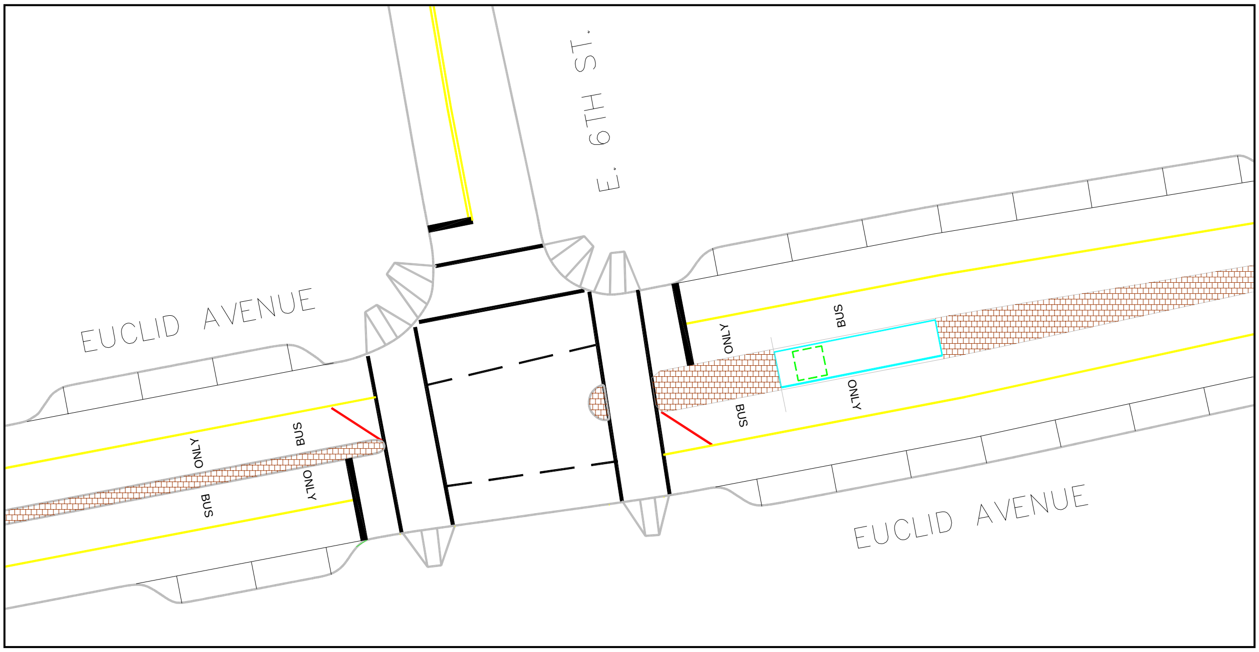


Figure C-2: Example of Bus Stop in Median with Left-Side Boarding and Alighting
(Source: Based on a Schematic provided by RTA)

The second section of the corridor is 3.5 miles long and extends from 17th Street to East 107th Street. Both local and BRT buses will operate in the median lanes of a four-lane divided roadway with other transit and emergency vehicles. Passengers board and alight from buses on the right hand side of the bus at stations on the far-side of intersections. Figure C-3 shows the intersection of 40th Street and Euclid Avenue, which represents a typical intersection for this section. The "island" stations will be placed between the left hand dedicated bus lane and the single right hand lane for general traffic. The bus lane alignment varies to accommodate stations within a single "envelope." Left turns from Euclid Avenue will be prohibited at station locations, but permitted at certain other locations.

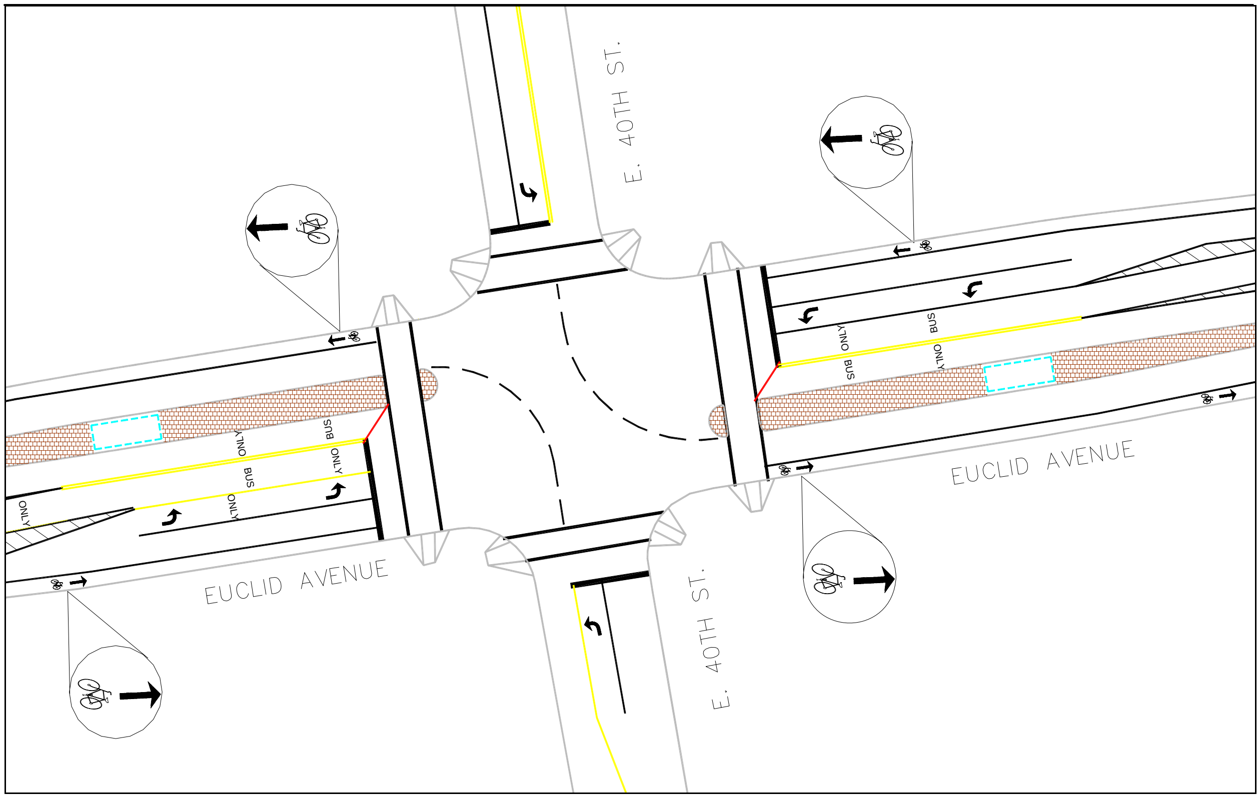


Figure C-3: Example of Bus Stop in Median with Right-Side Boarding and Alighting
(Source: Based on a Schematic provided by RTA)

The last segment of the corridor, east of 107th Street, is 2.5 miles long. Buses will operate in mixed traffic in the right hand lanes. This section is outside of the scope of the case study.

In the first two sections, the busway lanes will be separated from the general traffic lanes by grooved in rumble strips and white pavement markings placed on two-foot intervals at the midblock. The design incorporates a rotation of one-foot of grooved in depression of rumble strips followed by one-foot of solid reflective white pavement markings. The width of the grooves and pavement markings will be six inches wide. White pavement markings will be used rather than yellow pavement markings because vehicles in the adjacent lanes are going in the same direction.

The design team considered colored concrete or faded brick for the busway but both were cost prohibitive. As an alternate to this, a saw-cutting design will be cut into the pavement on a diagonal across the busway lanes. This will help to differentiate the busway lanes from the general purpose lanes. Figure C-4 displays the detail for the saw-cut and the rumble strips.

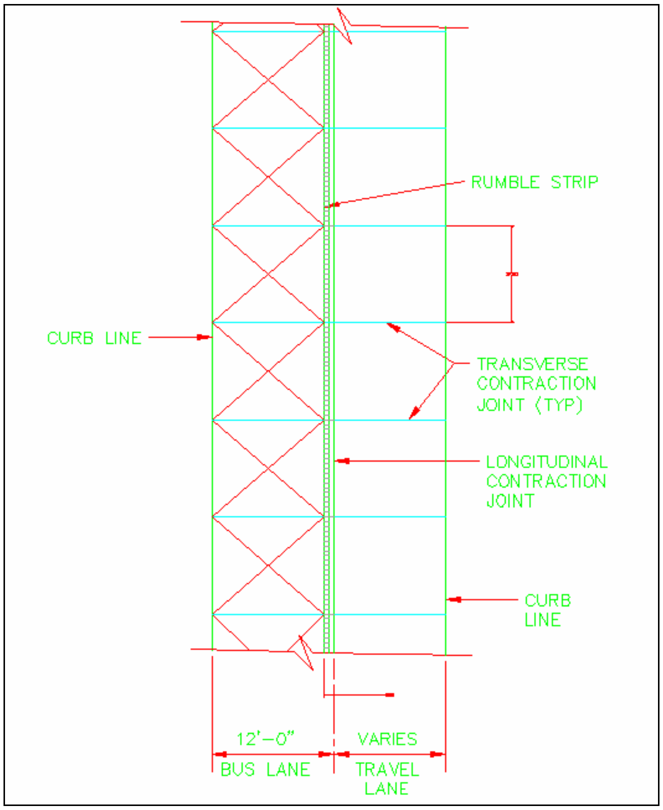


Figure C-4: Pavement Detail

Stations

The station stops will be equipped with bollards on the side and three bollards on the nose at the intersections. These bollards provide pedestrians with protection from errant vehicles. Additionally, they clearly identify the crossing area.

The station configuration varies along the corridor with both left and right-side passenger boarding and near and far-side stops. In the first segment, between Public Square and East 17th Street, the buses will operate in an at-grade, two-lane busway. The buses will be separated by a central landscaped median on the left and grooved painted rumble strips on the right, separating the busway lane from the general purpose traffic lane. The median will house a common station for buses operating in both directions. Passengers will board on the left-side of the busway, using the left side doors. The placement of the stop could be considered near or far-side, depending on the direction the bus is traveling.

The first three stations will consist of left curbside boarding at Public Square in downtown Cleveland. The proposed traffic pattern provides three, one-way, lanes running with a counterclockwise flow around the Square. The interior lane will be an exclusive transit lane around the Square.

The next four stations are common stations located in the median with left-side boarding. These downtown stations are flanked by a central landscaped median. The busway will be separated from the single traffic lane by the rumble strips with painted white lines described above. These seven stations will be used exclusively by the BRT vehicles and will only serve one bus at a time in each direction.

In the second segment, there will be 28 intersections and 15 pairs of stations (one for each direction). This section will also include three signalized, midblock pedestrian crossings, two of which are at stations. The signals at these midblock crossings will be pedestrian actuated.

The fifteen stations in this section are "islands" located in the median with right-side boarding located on the far-side of signalized intersections. The stations will be located between the left lane dedicated for buses and the right lane dedicated for general traffic. The grooved rumble strips with white pavement markings, as previously described, will separate the lanes. Stations were chosen to be located at signalized intersections to provide for the passenger's safe crossing to and from the adjacent sidewalks during the pedestrian signal phase.

Table C-1 presents the proposed busway stops and station configuration along the exclusive busway segment of the Euclid Corridor Transportation Project.

Table C-1: Busway Stops and Intersections

Busway Section	Busway Stations	Placement of Stop	Boarding Side
Section 1	Public Square: East Roadway North	Curbside	Left
	Public Square: West Roadway North	Curbside	Left
	Public Square: Tower City	Curbside	Left
	East 2nd Street Area	Median	Left
	East 6th Street	Median	Left
	East 9th Street	Median	Left
	East 13th (Star Plaza)	Median	Left
Section 2	East 18th/21st Street (Midblock)	Island	Right
	East 24th Street	Island	Right
	East 30th Street	Island	Right
	East 36th Street	Island	Right
	East 40th Street	Island	Right
	Near 5100 (Midblock)	Island	Right
	East 59th Street	Island	Right
	East 66th Street	Island	Right
	East 71st Street	Island	Right
	East 79th Street	Island	Right
	East 83rd Street	Island	Right
	East 89th Street	Island	Right
	East 93rd Street	Island	Right
	East 100th Street (Sundays Only)	Island	Right
	East 105th Street	Island	Right
	East 107th Street (Stokes/Streams)	Curbside	Right

The BRT buses in the first section will use a form of mechanically based precision docking systems at their stations. These types of docking systems minimize gaps between the station platforms and the bus. This will improve safety and access for all passengers especially those with special needs. The remaining gap is generally two inches or less which eliminates the need for wheelchair or ramp lifts. Precision docking systems also reducing boarding times as well as preserve the life of the platform edges and the bus wheels. Currently, the Euclid Corridor Transportation Project team is in the evaluation and testing stage of a precision docking system. Possible options to achieve the precision docking include integration of guide arm/wheel technology, use of radar-based products that detect and alert the operator when they are in proper alignment, lines painted into the pavement roadway parallel to the curb that operators would align with a fixed reference point, or mechanical “feelers” fixed to the body of the bus.

Entry and Exit Points

There are two transition points along the corridor. The first is from the first busway section with the central median to the second section with the raised island separating the busway from the general purpose lanes on the far-side of the intersections. In this first transition, buses simply continue in their lane and the raised islands transitions from the left-side of the bus to the right-side of the bus at the East 107th Street intersection. The second transition is from the second section to the third section with curb lane operation, this transition is aided by traffic signals. (This is discussed in the section on operations.)

Pedestrian Design

There will be no special channelization of pedestrians across the Euclid Avenue Corridor. However, the stations in the first section will include a 14” curb at the boarding platform. This height will likely discourage pedestrians from leaving the station at the platform and encourage them to walk to the end of the station and cross at the intersection. The edge of the platform is also equipped with a 24” truncated dome strip as a warning to pedestrians with visual impairments.

There will be ADA compliant ramps at the end of the station nearest the intersection to allow for easier access for people with disabilities.

Bicycle Design

A bicycle facility will be provided as part of the reconstruction. The proposed five-foot wide bicycle lane will run between Cleveland State University and Case Western University along the corridor. It will be approximately 3.5 miles long from East 22nd Street to Adelbert Road. The curb will be moved to accommodate the bicycle lane at fifteen intersections.

OPERATIONAL ASPECTS

Intersection Control

All intersections that cross the busway that meet signal warrants will be signalized. The few intersections that do not meet signal warrants will become T-intersections, allowing for right in and right out movements for the minor street.

Signals

The signal operations are still in the design stage. However, elements of the intersection operations that have been decided are discussed in the following sections.

Signal Hardware and Configuration

The busway will use three-indication white light transit signals as shown in Figure C-5. These will be placed on the same mast arm as the general purpose signals but will be accompanied by a sign stating "BUS SIGNAL ONLY". This sign is in the Ohio version of the MUTCD. The signals will be placed directly over the bus travel lane.

The busway signals will be encased in black casing. The vehicle signals will be encased in yellow casings. This difference in color is intended to distract general purpose motorists from the transit signal.

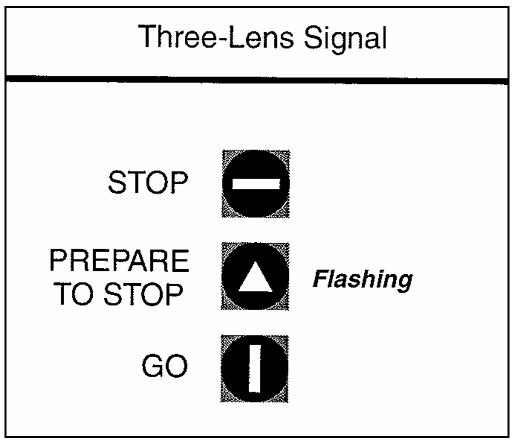


Figure C-5: Illustration of Three-Indication White Light Transit Signal

(Source: MUTCD)

Signal Operations

The signals along the corridor will employ six phases. This is displayed in Figure C-6. The mainline will operate with a leading and lagging protected left turn scheme. The busway lane will have the ability to have the go phase (white vertical stripe) both when the mainline through and right vehicle movements have green and in its own separate phase. The minor street traffic will operate split phased and therefore all minor street vehicle lefts will be protected. The mainline pedestrian crossings will be split with the minor street.

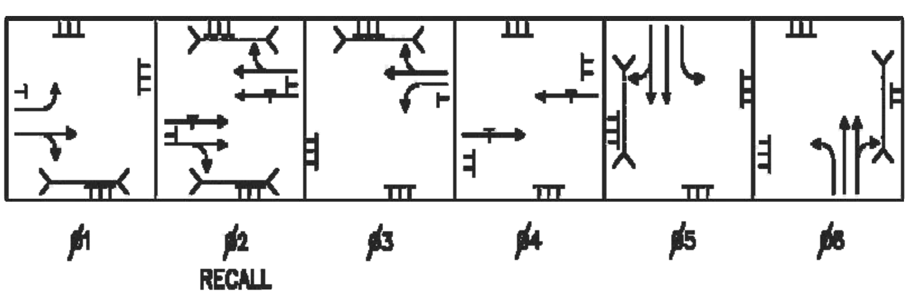


Figure C-6: Example Signal Phasing

The leading and lagging left turn phasing was necessary for the minor movement because of the geometry of the intersection. The opposing mainline left turns physically can not make their turns at the same time; the intersection is not wide enough to accommodate the opposing left turns concurrently.

Signal Timing

Most vehicle signals will have a 120-second cycle length. The yellow interval will generally be about 4 seconds with a 2-second all-red interval. At the time of the case study, the detailed signal phasing, timing, and coordination was not finalized for the corridor.

Left and U-Turns

Vehicle left turns will be protected only at the busway intersections. A separate left turn signal will be used with a red ball, left yellow arrow, and left green arrow. This signal will be equipped with a sign that identifies it as the left turn signal.

U-turns will be allowed at all intersections that have a left turn movement during the protected left turn phase. Trucks will be prohibited from making left turns. This will be communicated with a sign.

At the 12th Street intersection, there will be a left turn signal, however, there is no left turn there but instead a U-turn. The signal will be equipped with a supplementary sign that indicates that the signal is for U-turn movements and the lane will be marked with pavement markings.

Right turns on red from the minor streets will be prohibited to avoid conflicts between U-turning vehicles and right turning vehicles. This will be communicated with the standard MUTCD sign.

Signal Failure Mode

In signal failure mode, the general purpose lanes will receive a flashing yellow indication, the minor street will receive a flashing red indication, and the busway will receive the warning indication.

Signal Priority

Transit Signal Priority

The busway will employ a transit signal priority (TSP) system to reduce travel delays. Two types of TSP systems relative to transit will be used: conditional and unconditional. Conditional TSP systems can operate with a headway based system or a schedule based system. That is, priority is only provided to the bus in two conditions. First, if the bus is behind schedule it will receive priority. The second condition is if the headway between buses is longer than desired. Conditional priority can be very expensive to employ. The advantage is that it reduces the unnecessary demands on the cycle length. In this corridor, signal capacity is not a large concern at most intersections. Unconditional TSP provides the bus with priority every time the bus approaches the intersection.

The Euclid Corridor will employ unconditional TSP systems at the busway intersections including green extensions, early green, and the ability to jump phases. The green extension will be 10 seconds long. Each type of TSP can occur in one cycle. This will be accomplished through the use of an Eagle EPAC 300 device. These are similar to Opticom devices and are a form of light detection. Only the BRT buses are equipped with these. The detection is coordinated with the BRT bus door closing.

A few intersections cross roadways that are part of a coordinated north-south signal system. At these intersections, TSP will not be employed so that the coordination is not disrupted.

Although bus priority is important for the system, priority for the buses will not be provided at the expense of pedestrian safety. If a bus arrives at the start of the pedestrian phase, the buses will not receive the Go phase until the pedestrian phase completes the WALK and clearance interval.

Local Bus Detection

Initially, the Euclid Corridor Transportation Project team considered using loop detection at the intersections. However, loop detection involves considerable maintenance and is difficult to reprogram. The project team instead decided to use video detection. The video detection system will use a variable focal length camera. The programmable detection zone will be set at each of the intersections and can be modified if needed. The video detection will sense the presence of the bus and then communicate directly to the signal system. There is no need for communication between the bus and the signal system. However, the video system will not differentiate between an unauthorized vehicle and a bus. The BRT buses however, will communicate using the light detection system.

Signal Control at Entry and Exit Points

As previously discussed, there are two transition points along the corridor, one of which needs signalization to assist in the transition. This transition point will be equipped with an advance traffic signal indication for the buses so that they can maneuver across the general purpose lanes in advance of the general purpose lanes receiving the green signal indication. Video detection will be employed for the local buses. Light detection will be employed for the BRT buses.

Vehicle Signs and Pavement Markings

The Euclid Corridor Transportation Project team attempted to minimize signage to avoid visual clutter. This will minimize confusion and maintain the aesthetics of the intersection.

At the time of the case study, the traffic control plans had not been finalized for the project. This section reflects vehicle signs and markings that were proposed at the time of the study.

Guidance for Left Turning Motorists

Pavement markings, commonly referred to as “cat tracks” will be used to guide left turns through the intersection for cross street lefts turning across the busway. The threshold to the busway lanes will be equipped with diagonally-placed, red reflective raised pavement markers. These will serve to deter minor street left turning motorists from turning into the busway. Figure C-4 illustrates these measures.

Guidance Around Busway Median

The nose of the intersections at the station stops will be marked with a graphical sign for general purpose traffic to keep right of the median.

Signs and Pavement Markings to Deter Unauthorized Entry

The busway lanes will include pavement markings that say "BUS ONLY" at the intersection approaches. These pavement markings are also used in the midblock at various intervals along the busway.

The rumble strips separating the busway from general purpose traffic and the saw-cut pavement on the busway lanes will also deter unauthorized entry.

Pedestrian and Non-Motorized Users

All signalized intersections will be equipped with countdown pedestrian crossings on one or more of the approaches. These signals will be encased with yellow backgrounds for better visibility. The pedestrian countdown signals are an extremely important element of the pedestrian control. They allow pedestrians who depart the bus in the median of the intersection to see how much time is remaining in the pedestrian clearance interval. Since the clearance interval is based on the entire crossing distance, the delay to pedestrians is reduced with countdown signals compared to traditional signals.

The pedestrian signals will be actuated with a pedestrian pushbutton. The proposed pushbuttons are to be ADA compliant with both vibrotactile and audio functions to communicate to the pedestrians when to cross. The design team worked with different community groups to select the appropriate pushbuttons. The pushbuttons signals were piloted near a retirement home and found to be acceptable.

The design team considered using split pedestrian walk signals. That is, the pedestrian would cross the roadway in two phases with a stop in the median. This would be useful for discharging transit passengers from the median stations. However, it was determined that the pedestrians could see the far-side WALK signal and may enter the intersection prematurely.

Unauthorized Entry

Road Pavement Markers (RPM) are proposed to be installed on the diagonal at the entrance to the busway. These RPMs are to be reflective, red, and are intended to deter left turns from turning into the busway. The design team expressed some concern about the using RPMs in an area with seasonal snow. To combat this, the RPMs are to be embedded into the pavement.

SAFETY

As this system is still in the design phase, the expected safety performance of the busway intersections is unknown. However, there are many changes to the design and operation of the corridor will likely have a positive effect on safety. The first section of the busway with the center median bus lanes is being converted from a four-lane undivided facility to a four-lane divided facility. Four-lane divided facilities generally have fewer crashes than their undivided counterparts. Additionally, many of the minor intersections on this segment are being converted to T-intersections. Because of the reduced movements and conflict points, a decrease in crashes at these intersections is likely.

The proposed busway speed limit is 35 MPH while the general purpose traffic speed limit will be 25 MPH. This difference in approach speeds may be a concern at intersections, particularly for pedestrians who enter the intersection during the bus right of way.

Safety was considered in multiple parts of the BRT vehicle design. The new vehicles are equipped with cameras and Clever Device Object Detection that will warn drivers of objects potentially in their path. The positioning of the vehicles' mirrors was also a concern. The mirrors are positioned higher. This was needed because the platforms are higher in the first section.

The project team is preparing standard operating procedures (SOPs) and a training program that have a large impact on safety operation. The operator training will include a scan and search procedure for operators to be aware of potentially dangerous situations such as pedestrian crossings or automobile U-turns in front of buses. Operators will receive additional training in customer service; 60-foot articulated bus operations and precision docking; signals; and a cultural reorientation for a brand new type of service The SOPs and training programs will eventually be incorporated into the System Safety Plan. There will also be an observational period at the start of the operation of the corridor that will identify safety concerns. To ensure customer service and safety, the program will be launched with station monitors and ride checks.

PUBLIC INFORMATION CAMPAIGN

Public information and community involvement are important component to this project. Community meetings, marketing outreach, marketing distribution, construction alerts, and press releases are coordinated in a master schedule to ensure that the public is adequately informed.

The Euclid Avenue Corridor Project team has used various forms of communications to inform the public about this project. These have included post cards and newsletters sent to mailing lists, media such as television spots, and community outreach. The public information material is provided in English.

Euclid Avenue Corridor Project team identified 45 distribution sites to talk with those who will be impacted with the project. These sites include libraries, universities, churches, social services, and businesses. The team concentrated on locations with high pedestrian volumes in a five to ten-mile radius from the project.

Construction alerts and updates were also printed in newspapers, aired in television spots, posted near the project, and sent to mailing lists. There is also a project website, hotline, and an email list.

A 7-minute project video was developed that describes the project. The project video is available on the project website and is distributed on CD. The narrative video provides background on the project, project ridership, an overview of the stations, information on the project design, and a description of the vehicles.

A Community Involvement Handbook was developed for the project. It provides information on the project, a description of the rapid transit system, milestones and scheduling information, and contact information.

The project website, www.euclidtransit.org, is updated regularly and provides information on all upcoming events, copies of marketing materials, and contacts for additional information. The website is supplemented by a project hotline.

APPENDIX D
LOS ANGELES COUNTY METRO ORANGE LINE

BACKGROUND

The Metro Orange Line (MOL) is a 14.2-mile busway in the San Fernando Valley area of Los Angeles County. Completed in October 2005, it connects the mature suburbs and urbanized areas as far as the Warner Center with the North Hollywood Metrorail Station. The MOL operates on 13 miles of dedicated lanes. The MOL route is shown in Figure D-1.

The MOL right-of-way is exclusive within the median of a Chandler Boulevard right-of-way for approximately five miles, where it operates within an 80-foot space previously occupied by rail operations. In the remaining nine miles of the corridor, the MOL operates in a 100-foot former railroad right-of-way along portions of Friar and Oxnard streets and Victory and Chandler boulevards.

The project team visited Los Angeles in December of 2005 to conduct the case study. The project team met with representatives of The Los Angeles Metropolitan Transportation Authority (subsequently called "Metro"), which operates the Metro Orange Line, and the Los Angeles Department of Transportation (LADOT). Case study participants included the following individuals:

- Gary Spivack, Transportation Manager, Metropolitan Transportation Authority
- Maria Reynolds, Division Transportation Manager, West San Fernando Valley Division, Metropolitan Transportation Authority
- George Trudeau, Assistant Transportation Manager, Metro San Fernando Valley, Metropolitan Transportation Authority
- Michael C. Hunt, P.E., Transportation Engineering Associate III, Department of Transportation, City of Los Angeles
- John Fisher, P.E., P.T.O.E., Assistant General Manager, Office of Transportation Operations, Department of Transportation, City of Los Angeles
- Kathleen Sanchez, Transportation Planning Manager, Metropolitan Transportation Authority
- Morteza Delpasand, P.E., Transportation Engineer, Department of Transportation, City of Los Angeles
- Robert H. Torres, Corporate Safety Manager, Corporate Safety, Metropolitan Transportation Authority
- R. Scott Page, Transportation Planning Manager IV, Regional Transit Planning, Metropolitan Transportation Authority
- Hitesh Patel, P.E., Director, Construction Project Management, Metropolitan Transportation Authority
- Vijay Khawani, Director, Corporate Safety and Rail Operations, Metropolitan Transportation Authority

Figure D-1: The Metro Orange Line Route

The MOL buses operate from 4 AM to 1 AM, seven days a week. Service frequency consists of five to six minute headways during weekday morning peak (5:30 AM to 9:30 AM) and afternoon peak (3:30 PM to 6:30 PM) During the off-peak weekday hours, buses operate every 10-12 minutes during the day, and every 15-20 minutes during the early morning and late night hours, seven days a week. On the weekends, service frequency will consist of 10-20 minute headways. MOL buses currently stop at every station.

The fare for the system is $1.25 (current as of 2006) in each direction, or $3.00 for a day pass. The system is a proof of payment system so the fare is purchased prior to boarding the bus.

Spaced approximately one mile apart, the Orange Line includes 13 stations at major activity centers such as Valley College, the Van Nuys Government Center, and Pierce College while also serving high-density commercial development along Ventura Boulevard. There are park and ride lots built at six of the stations, providing more than 3,200 parking spaces. There are a total of 44 signalized intersections along the 14 mile corridor, including four midblock pedestrian crossings.. Thirty-six of the 44 intersection crossings are along the 13-mile dedicated ROW, all of which are at-grade. There are over eight miles of pedestrian and bicycle paths along the route.

There are 30 new state-of-the-art articulated, low floor, compressed natural gas (CNG) buses that serve the Metro Orange Line. The buses are 60 feet long, 102 inches wide, and have a seating capacity for 57 passengers. There are three doors for boarding and alighting, two wheelchair securement areas, and two bike racks inside the vehicle. The three doors and the low floor design help to expedite boarding and alighting. The front door ramp deploys in 25 seconds for wheelchair and other mobility assistance.

The CNG buses are quiet in operation. Although the busway is equipped with sound walls in residential areas, the buses are much quieter than the roadway was designed to accommodate.

Capacity concerns since the inception of the system in October 2005 have prompted Metro to consider running an express bus along the busway. There are two lanes adjacent to each station so buses can pass one another.

DESIGN

General Design

The Orange Line is constructed in 80’ right-of-way in the eastern segment and 100’ right-of-way for the rest of the busway. The entire busway is 14.2 miles long with 13 miles of dedicated busway. The busway surface is rubberized asphalt and concrete. The width of the pavement along the busway is at least 26’ wide. The buses are 11.5’ wide including the mirrors on both sides.

Most, but not all of the intersections are at 90 degrees. There are a few intersections that are skewed. An example of this is the intersection of the busway and Woodman Avenue.

There are 12’ high sound walls installed along the busway, mostly in the residential areas. There are over seven miles of the busway with sound walls. These sound walls are constructed 10 to 15’ behind the property lines.

The Metro staff describe the busway alignments as having five types of intersections:

- Median alignment;

- Diagonal crossing;
- Cross/Parallel street (independent intersections);
- Right turn pocket (side aligned intersections); and
- Midblock pedestrian crossing.

Each of these intersection types are described in the following sections.

Median Alignment

The two-mile eastern segment of the busway is a median aligned busway. The busway travels in the large median of Chandler Boulevard which is an east-west route. Chandler Boulevard is split by the median into two one-way streets (Chandler Boulevard North and Chandler Boulevard South) with two lanes in each direction.

There are nine signalized intersections along this section including the following major intersections:

- Tujunga Avenue,
- Laurel Canyon Boulevard,
- Whitsett Avenue, and
- Coldwater Canyon Avenue.

Seven of the intersections are single-point intersections and two are midblock pedestrian crossings. There are left turn pockets at each intersection for eastbound and westbound Chandler. Left turns are protected only and proceed on a single phase. The single point intersection design was used so that the lefts could operate together with the available space. Left turns are guided through the intersection with pavement markings.

There are two stations in this section. The eastern terminus, the North Hollywood station, is a transfer point to the Metro red line. The second station is the Laurel Canyon station.

Diagonal Crossing

The busway also includes a diagonal intersection at the intersection of Fulton Avenue and Burbank Boulevard. That is, the busway crosses diagonally across this four-legged intersection from the southeast corner to the northwest corner of the intersection.

Independent Intersections

These intersections operate simply as independent or isolated intersections. Vehicles are allowed to store between the busway and the parallel streets. Some of these intersections are skewed.

Side-Aligned Intersections

In the western section of the busway, the busway is side-aligned to Oxnard Street/Topham Street/Victory Boulevard for 4.5 miles. The busway is on the north side of this east-west roadway. Metro refers to these side aligned intersections as right-turn pocket intersections. There are eight of these intersections. At these intersections, the busway and roadway function together as one intersection.

Midblock Pedestrian Crossings

There are four, signalized midblock pedestrian crossings. These are described in the section "Pedestrian Design."

Stations

As noted earlier, there are 13 stations along the MOL. The stations are 180 feet in length, long enough to accommodate three articulated buses. The busway widens at the station areas, allowing other buses to pass a stopped vehicle safely.

Most stations are located on the far side of the intersection. This was not possible at three stations (Van Nuys, Woodman, and Balboa) due to right-of-way constraints so the westbound stations are nearside. Metro prefers far-side stations to allow the bus to clear the traffic signal prior to boarding and alighting passengers.

The stations feature original art as well as lighting, seating, security cameras, public telephones, bicycle racks, and ticket vending machines. Station signs display real-time vehicle arrival information.

All of the stations are at signalized intersections with pedestrian crossing markings. Pedestrians are guided to the nearest sidewalk via signs and signals.

Entry and Exit Points

Orange Line buses only travel on the busway and would only leave the busway in an emergency. Therefore, the only entry and exit points are on the eastern and western end. Although they are not being used at this time, entry points at Sepulveda and Reseda have been designed.

The eastern terminal for the busway is at the North Hollywood Red Line station. The station has a turnaround for buses. Buses enter and leave the station with the assistance of a traffic signal. This station is a layover station for operators.

On the western end of the Orange Line, buses leave the busway at Variel Avenue and Victory Boulevard. The buses travel on surface streets to Warner Center and then loop back to the busway. Warner Center station is also a layover station for operators.

Pedestrian Design

There are four midblock pedestrian crossings. They are located near the following intersections:

- Agnes Avenue and Chandler Boulevard
- Goodland Avenue and Chandler Boulevard
- Havenhurst Avenue and Busway
- Zelzah Avenue and Busway

Most of these crossings are equipped with pedestrian push buttons to activate a signal. At the Goodland Avenue and Agnes Avenue midblock crossings, which are on a section of the busway with a closely spaced, parallel street (i.e., along Chandler Boulevard), the pedestrian crossing has a "zigzag" design illustrated in Figure D-2. This is to deter pedestrians from crossing the busway and the parallel street in one movement. There is ample room for pedestrians to store in the median, between the parallel street and the busway.

Figure D-1: Graphic Illustrating Zigzag Design at Pedestrian Crossings

The use of pedestrian actuation at the pedestrian crossings was a concern. Metro preferred to have the busway always see green unless a pedestrian actuated the signal. LADOT prefers to have the signals rest in red and only turn green if the pedestrian or an approaching bus actuates the signal. The buses get priority and have a green signal on the approach as long as there is no pedestrian phase currently activated. There is some concern that pedestrians will not push the button and wait to cross.

LADOT considered using motion actuation instead of push button actuation for the pedestrians. However, they have had some issues in the past with motion actuation and decided to use push button actuation.

The single point intersections were designed with storage landing areas so that pedestrians do not have to cross the busway during one single phase, although it is possible to do so. The intersections are currently equipped with the MUTCD push button sign.

Bicycle Design

The MOL includes a 14-mile bikeway, 8 miles of which is concurrent with a pedestrian path. The bicycle/pedestrian path is 17' wide except in a few sections where the available right-of-way is constrained. The bicycle path allows for two directions of travel separated by a dashed yellow line. The pedestrian walking area is separated from the bicycle area by a double white line with a diagonal hatch pattern. The path is separated from the bus travel lanes by a fence. The bicycle/pedestrian path is pictured in Figure D-3. All stations are equipped with bicycle lockers and racks. Bicycles are also allowed on the buses.

Figure D-3: Bicycle/Pedestrian Path along the Metro Orange Line

At the eastern section of the busway where the busway is in the median of Chandler Boulevard, the available right-of-way becomes too narrow for a bike path. In this section, there are 2.3 miles of on-street bike lane and no adjacent pedestrian path.

OPERATIONAL ASPECTS

General Intersection Control

All busway intersections are controlled by traffic signals, including the five midblock pedestrian intersections. New Type 2070 controllers govern the traffic signals for automobiles, pedestrians, and buses at the intersections. There will be no rail-style gates at any of the intersections.

The cycle lengths along the busway vary by intersection. Most are either 90 seconds (smaller intersections) or 120 seconds (larger intersections). There are six signalized intersection that are in "free" operation. That is, the signal phase only changes in response to actuation. Four of these intersections are the signalized midblock pedestrian crossings. The remaining two are the intersections of the busway with Tyrone Avenue and with Vesper Avenue. Both intersections are low volume intersections and currently are not affected by the operations of the major downstream arterial, Oxnard Avenue. However, if volumes increase at the intersections, there is a potential that the queue for Oxnard Avenue on either roadway could back over the busway at these intersections. If the volumes increases, the cycle length at the intersection would become fixed to prevent queuing over the busway.

Bus Signal Control

The busway intersections are equipped with traditional traffic signals. Light rail signals or transit signals were not considered appropriate for the busway.

The busway signal heads have green through arrows instead of green ball indications. No turns are allowed from the busway except in emergency. The yellow and red indications are balls. A supplementary sign identifies the signals as bus signals.

Pedestrian Signal Control

Pedestrian crossings are equipped with traditional pedestrian signals at most intersections and pedestrian countdown signals at high volume crossings. As previously noted, there are four midblock pedestrian crossings. These pedestrian crossings are also equipped with a special busway approaching LED signal. This is illustrated in Figure D-4. The LED indication of the bus flashes when a bus is approaching.

Figure D-4: Pedestrian Signal Bus LED Indication

Vehicle Signal Control

Through Movements

For vehicle traffic crossing the busway, only green arrows are used for all through movements.

Right Turn on Red Prohibition

Right turn on red is prohibited with a red arrow and a nearside and farside No Right Turn (Symbol) on red static sign at the side-aligned intersections. In California, the red arrow must be used to prohibit right turn on red. They do not use a right turn signal sign. These intersections are also equipped with LED bus signs. These signs are larger than the pedestrian LED signs and include the text "BUS" under the symbol of the bus.

On the west end of the busway, the through traffic on Victory originally had a green ball in the lane closest to the right turn lane. However, this was changed to a green arrow to further clarify and emphasize that vehicles are prohibited from turning right from that lane.

Left Turns

Left turns are from the arterial are allowed across the busway at the median arterial intersections and the side-aligned busway intersections. At these intersections, left turns from the parallel roadways are protected only. At the median arterial intersections, left turns are before the parallel through phase (i.e., leading left turns).

Transit Signal Priority

The buses are equipped with transponders for priority. The busway is also equipped with advance in-pavement loop detection. There are 151 bus loops along the busway (141 of which are on the dedicated right of way). If the buses stay in progression, they should receive a green when they approach most of the intersections. However, due to heavy pedestrian and vehicular cross traffic volumes, a green cannot be guaranteed.

Transponders on the buses are detected by sensor cards in the cabinet that are hard-wired to the advance bus loops. Without the transponders, the sensor cards would not detect the buses. To minimize false detections from buses going the opposite direction, the sensor cards require both the metal bus and the transponder to be detected. The transponders are also used to prevent bunching. That is, the system can decide not to provide a green interval for an approaching bus if it is too close to the next bus.

There are also failsafe loops at the intersections. That is, if the advance loops are not activated for some reason, there are loops at the intersection that will provide a green signal for a bus or other vehicle that is waiting at the signal. The loops at the intersection do not require a transponder to actuate.

The busway is an east-west route. There are significant traffic volumes on some of the north-south arterials that intersect with the busway. Because of the need to keep the north-south traffic in coordination, the cycle lengths at the intersections are fixed.

Signs and Pavement Markings

The LADOT representatives noted that the intersections have many traffic control devices including signs and signals. They stated that additional traffic control devices will be reviewed thoroughly prior to installation to ensure they are not adding visual clutter that may reduce the effectiveness of all devices at the intersection. The following sections describe the signs and markings that are currently used.

Guidance for Left Turning Motorists

Pavement markings guide left turning motorists through the single point intersections. The pavement markings are yellow and are referred to as “cat tracks.” Although the signals are programmed visibility, the busway signals are equipped with a supplementary “BUS SIGNAL” sign so that east and westbound left turning motorists do not confuse the bus signal with their own at the single point intersections.

Prohibiting Turns onto Busway

At the independent busway and the side-aligned busway intersections intersections, turns are prohibited onto the busway with a variety of signs. A “NO TURNS” sign is placed overhead on the signal mast arm. Graphical signs prohibiting turns are placed to the right and left on the intersection respectively. These intersections also have a yellow graphical BUS XING sign on the intersection approaches. This sign is displayed in Figure D-5. This sign was developed by LADOT staff. The bus graphic on the sign is based on the outline of the Orange Line buses.

Figure D-5: Busway Crossing Warning Sign

At the all of the busway entry areas, regardless of intersection type, "DO NOT ENTER" signs are equipped with supplementary "TRANSIT VEHICLES EXEMPT" signs. "BUS ONLY" pavement markings are also at all of the entry areas.

Busway Street Name Signs

Busway intersections are equipped with street name signs that identify them as "Busway." This helps to identify the presence of the intersection for the independent intersections and heightens awareness of the presence of the busway for motorists and pedestrians. LADOT uses blue signs with white lettering to identify streets names. This is the color scheme used for the busway name signs.

Keeping Vehicles out of the Intersections

Some of the intersections have pavement markings with the message "KEEP CLEAR" in the center of the intersection. KEEP CLEAR pavement markings are installed where there is a potential for vehicles queuing over the busway. The pavement markings are intended to deter vehicles from queuing over the busway. At signalized intersections where it may not be clear, STOP HERE ON RED signs and WAIT HERE pavement markings are used. If the distance between the busway and the next intersection is 100', they allow vehicles to store between the two but they are not allowed to queue over the busway intersection.

Pedestrian and Non-Motorized Users

Overhead "PED XING" signs are used at the four signalized, midblock pedestrian crossings to alert the bus operator to the presence of the crossing. The signs are yellow with black letters.

The bicycle/pedestrian paths are signed to deter motor vehicles from entering the path and to instruct pedestrians and bicycles of the appropriate placement in the path. This is displayed in Figure D-6. There are two lanes, one in each direction, for bicycle traffic.

Figure D-6: Signs at the entrance to Pedestrian/Bicycle Path

All crosswalks are marked with pavement markings at the intersections and at the four midblock crossings.

The bicycle path uses “SLOW” pavement markings on the approach to intersections to warn bicyclists to slow down as they approach the intersection. There are also SIGNAL AHEAD signs located on the approaches to signalized intersections.

Unauthorized Entry

The busway is only for Orange Line buses. Emergency vehicles are only allowed on the busway during a pursuit. Even METRO supervisors are not allowed to use the busway.

Metro is using “positive law enforcement” to deter pedestrians, automobiles, and bicyclists from using the busway. Positive law enforcement means that law enforcement is visible on the busway. Motorists who are caught using the busway will receive a citation. The fine for jaywalking is $271. The fine for trespassing is $500. The busway is marked with private property signs that prohibit trespassing, parking, and dumping.

BUS OPERATIONS

Bus operators for the Orange Line underwent a three-step training program including class training, on-street training (non-busway), and training on the busway. Operators are given eleven hours of training for the articulated buses. They are trained for both daytime and nighttime operation.

The Orange Line is a high seniority line. Operators like the line because of the proof of payment system.

If Metro finds that sight obstructions or other visual barriers exist along the busway, they will issue "be prepared to slow" orders for the bus operators.

SAFETY

Metro anticipates two safety issues at the busway intersections based on the operations to date: right turns on red into the path of the busway and through vehicles running red lights. Red light running has been an issue at several intersections including the intersections of the busway with Mason Avenue, Corbin Avenue, and Kester Avenue.

At the time of the December 2005 site visit, the MOL had been in operation for just over one month. Two crashes occurred three days after the opening of the system. The first, a minor crash, resulted after a driver made an illegal right turn on red into the path of a bus on the busway. The second crash resulted in injuries and occurred later that day. A woman ran a red light at a busway intersection and struck a bus. The driver was reportedly talking on her cell phone.

Safety Task Force and Remediation

The Metro Orange Line Safety Task Force was established to review current practices and procedures, and where necessary, implement changes. The Task Force includes members from Metro Operations, Metro Safety, Los Angeles Department of Transportation, Los Angeles Police Department, Los Angeles County Sheriff Department, and Metro Construction.

In response to the crash experience at the start of the MOL operation, the following measures were put into place:

- <u>Temporary Operating Speed Reduction</u>. The operating speed was originally 25 to 35 mph through intersections, but was lowered to 10 mph. This lowered speed limited was a temporary restriction. They are considering rescinding this lowered limit.
- <u>Signal Timing Modifications</u>. In order to accommodate the lower speed limits of the buses through the intersection, the bus phase had to been lengthened. The all-red phase was also lengthened to reduce the chance for conflicts at the end of the phase and the start of the next phase.
- <u>Modification to Right Turn on Red Prohibition Signs</u>. Near side and far side right turn on red prohibition signs were lowered to align with active LED "Bus" signs for enhanced visibility.
- <u>Signal Indication Changes</u>. A green through arrow replaced the green ball at the through signal closest to the busway at the side-aligned intersections on the western section of the busway. This was intended to reinforce the turning movement prohibitions.
- <u>"BUS XING" Signs</u>. Static "BUS XING" signs were installed at all busway intersections. The graphical yellow warning sings are installed on the north-south vehicle approaches to the busway intersections. The sign was created by LADOT staff and includes a graphical bus patterned after the Orange Line buses.
- <u>Bus Mounted Strobe Lights</u>. Four white strobe lights were installed on two test buses to increase vehicle visibility.

In addition to these measures, enforcement and public information were also increased. As a temporary measure, City Traffic Control Officers were stationed at key intersections along the busway. Patrols have also been increased on or near the Orange Line by the LAPD and the LASD. Metro continues to conduct public information campaigns including safety education brochures, safety presentations at schools, and safety advertising campaigns in major newspapers.

At the time of the case study, additional safety actions were in progress, including the following measures:

- Active LED Bus Signs. Additional active LED "BUS" signs will be installed on all traffic mast arms at busway intersections for cross traffic to enhance warning of buses approaching. On the west end of the busway, the signs will replace the far-side programmed visibility signals. Many motorists were confused by these programmed visibility heads and did not think the signals were functioning because they could not see them from a distance.
- Active LED Bus Signs for Pedestrians. Additional active LED "Bus" symbol signs will be installed at limited visibility intersections for pedestrians to enhance warning of approaching buses.
- "LOOK BOTH WAYS" Signs. Passive 24-inch "Look Both Ways" signs will be installed at all intersections. The sign uses the same LADOT graphic as the "BUS XING" sign.
- Photo Enforcement. Photo enforcement of red light running will be installed at 12 high-risk intersections. The first intersection is under construction.

The Task Force is also evaluating additional intersections for the use of "KEEP CLEAR" pavement markings. The markings are already installed at a few intersections where the potential for queuing across the busway exists. The markings are placed in the center of the intersection to deter vehicles from queuing over the busway.

At some intersections, there is some concern that the sound walls may obstruct the line of sight at the intersection. Metro is going to review a few locations and may remove panels to increase the sight distance. The original design had the sound walls placed far enough back from the intersection that they did not obstruct the sight lines however; there may have been some changes during the construction phase that was not in the design. The original design sight distance was based on the sight distance for both the buses on the busway and the vehicles on the intersecting roadways under Caltrans standards. The safety of pedestrians was also considered.

Near Miss Report

In response to safety concerns after the opening of the busway, the bus operations supervisors developed a "near miss" report. Bus operators record near misses that happen during their route. Operators classify near misses as one of the following activities:

- Other vehicle fails to stop for Red Light
- Other vehicle on a parallel street turns across Busway - against signal
- Pedestrian crosses Busway against signal
- Unauthorized vehicle traveling on Busway
- Vehicle on cross street stopped on Busway
- Unauthorized Pedestrian/Bicyclist on Alignment – between intersections

- Bicyclist crosses Busway- against signal
- Pedestrian crosses Busway - not in crosswalk
- Vehicle attempts to enter onto Busway

The operator identifies the intersection where the near miss occur and the time and date of the near miss. The bus operations supervisors are tracking these reports in order to identify potential problems before a crash occurs.

During the one-month period from November 4 through December 4, there were 706 reported near misses including:

- 221 (31 percent) “Other vehicle fails to stop for Red Light”
- 130 (18 percent) “Pedestrian crosses busway against signal”
- 50 (7 percent) “Unauthorized vehicle traveling on busway”

Near misses have decreased significantly since they started to track their occurrence. This is likely due to the safety improvements implemented by the Task Force, but also due to time. That is, some of the crashes and near misses the occurred at the opening of the busway was likely due to the unfamiliarity of the intersections. However, motorists and non-motorized users have become more familiar with the busway intersections since the opening. The public information campaign and media coverage of the crashes has also raised awareness of the intersections.

PUBLIC INFORMATION CAMPAIGN

Metro has made a concentrated effort to provide public information about the new Orange Line. Metro developed a safety video about the busway. It was taken to over 100 schools in the area. They also developed a project website. The website has a section to advise the public of the status of the project and what it will provide for passengers.

Local newspapers were also used to inform the public about the Orange Line. A special section ran in the local papers that introduced the Orange Line and discussed safety of the system. The agency expects to continue to work extensively with local and regional media outlets to provide other channels of information to the communities surrounding the Orange Line.

The public information campaign also included a stakeholders group. During the development of the busway, the stakeholders group was formed as part of the public outreach efforts. The stakeholders group included 120 representatives from businesses and the community.

RECOMMENDATIONS FOR OTHER AGENCIES

Because of the width of the buses including their mirrors, Metro staff recommends using pavement that is at least 15’ wide in each direction of travel. Their pavement is only 26’ wide and caused concern among the bus operators.

The interviewed representatives were asked if colored pavement was considered for the busway. The original design included concrete intersections with colored crosswalks. The colored crosswalks were removed from the design out of a concern for maintenance. However, Metro staff indicated that colored pavement would be useful to increase the awareness of the busway intersections. The majority of the crossings are concrete which contrasts nicely with the asphalt concrete cross streets. There are only a few intersections that have rubberized asphalt concrete pavement.

APPENDIX E
LYMMO BUS RAPID TRANSIT DOWNTOWN CIRCULATOR

INTRODUCTION

The LYMMO Bus Rapid Transit downtown circulator was created by the Central Florida Regional Transportation Authority (LYNX), the City of Orlando's Downtown Development Board, and The Community Redevelopment Agency in order to add capacity to the downtown transportation network. It is a three-mile loop that connects parking ramps on the exterior of the city to major downtown generators such as the TD Waterhouse Arena, the Courthouse, City Hall and major office towers.

The first downtown Orlando circulator was the Meter Eater that was introduced in 1983. That system provided transit service between the downtown core and parking garages located along the perimeter of the downtown area for a nominal fee of $0.25. In 1984, the system was later sold and the FreeBee system began operating providing the same service for free. In 1994, the LYMMO downtown circulator system was approved and design of the project began with the new system operation beginning its free service in August of 1997.

The project team visited Orlando in mid-December 2005 to conduct the case study. The project team met with representatives from LYNX, the City of Orlando, and transit operators and trainers. The service is owned by the City of Orlando and operated by LYNX. Case study participants included the following individuals:

- Doug Jamison, LYNX Project Manager, Planning
- Keith Tillet, LYNX Assistant Chief Supervisor
- Jerry Spruiel, LYNX Training Supervisor
- Jennifer Clements, LYNX Deputy Director of Planning
- William E. Zielonka, LYNX Safety & Security Operations Support Division
- Thomas Holland, City of Orlando
- Albert Perez, City of Orlando
- Charles Ramdatt, City of Orlando
- Daisy Staniszkis, Assistant Director, Downtown Development Board
- Richard A. Cima, P.E., GAI Consultants

LYMMO buses operate in dedicated lanes that are separated by a curbed median in some sections and raised pavement markers in others. LYMMO buses are 35', low-floor vehicles that operate on compressed natural gas (CNG). The buses operate with 4-minute headways in the peak, 10-minute headways in the daytime off-peak, and 15-minute headways at other times. Total travel time for the system is between 18 and 20 minutes. The service has a ridership that averages over 90,000 riders per month and continues to exceed ridership projections. There are thirteen stations and eight stops along the downtown circulator. The route is pictured in Figure E-1.

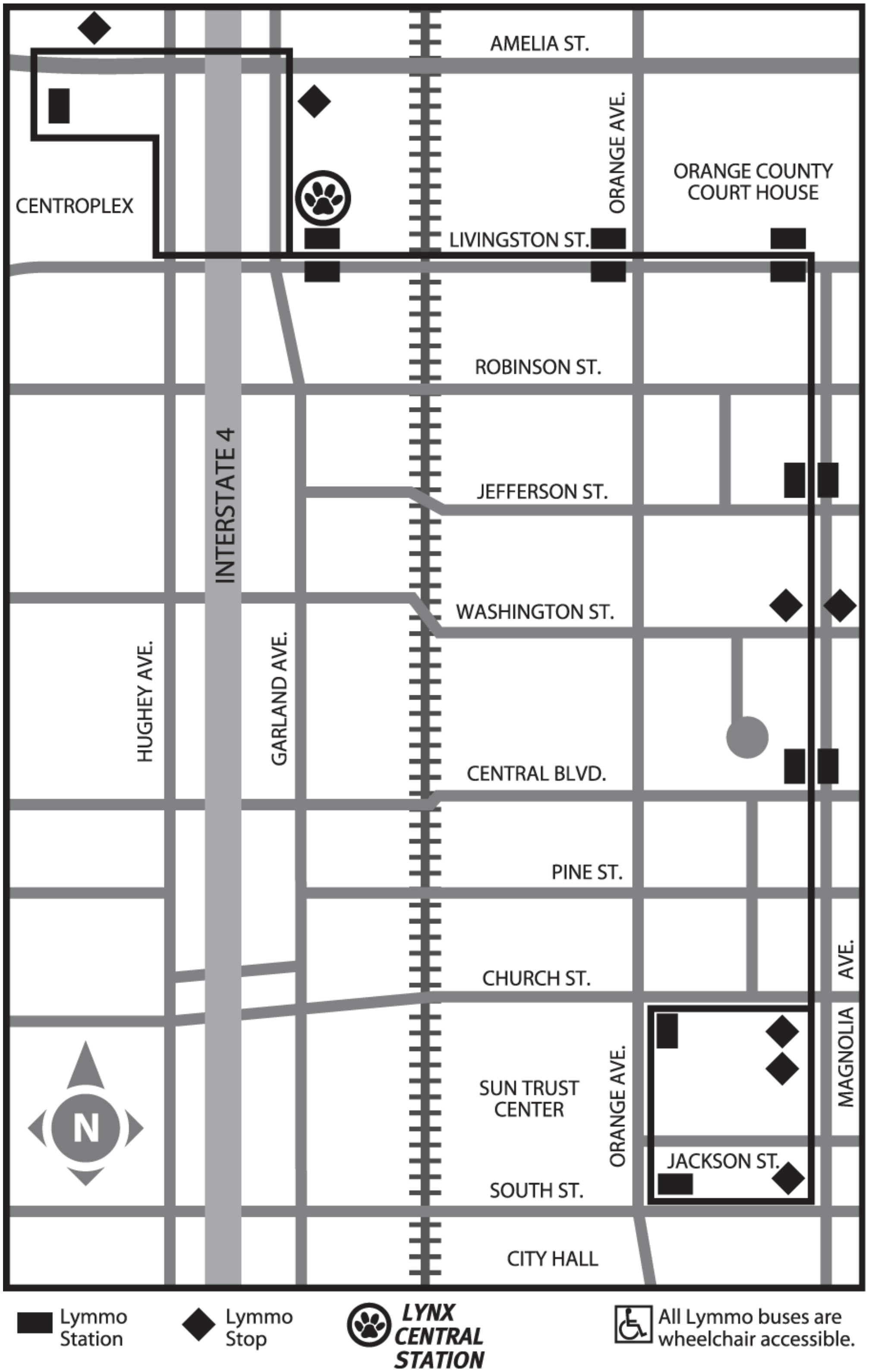


Figure E-1: LYMMO System Map

Only LYMMO buses are allowed in the busway with the exception of the intersection of Livingston Street at the LYNX Central Bus Station just east of Garland Avenue. At this intersection, non-LYMMO buses are also allowed to use the busway lanes. This is necessary for traffic flow into and out of the Garland Station.

The primary goal of the LYMMO system is to help vehicles destined to the downtown area to park once and to increase transit trips within the downtown as well as enhance pedestrian movements. The LYMMO system also provides maximum transfer access to the LYNX downtown bus station and future multi-modal station located on Garland Avenue between Livingston Street and Amelia Avenue.

DESIGN

General Busway Design

Because of the dense urban environment along the LYMMO route, engineering judgment was often used instead of specific standards were used throughout the majority of the corridor.

The LYMMO system is a continuous loop consisting of buses traveling on exclusive lanes paved with distinctive gray pavers. The busway is separated from general traffic with a combination of raised medians or a double row of reflective ceramic pavement markers embedded in the asphalt. Between the end loops of the LYMMO route, the buses run in two directions with one bus running contraflow to the adjacent general use lane(s). All bus movements at intersections are controlled by special bus signals in order to prevent confusion with the general use signals. Regulatory signage for vehicles consists mainly of “DO NOT ENTER” signs and turning restriction signs along with “BUS ONLY” pavement markings.

Beginning at the north loop, buses travel with the flow of traffic on Garland Avenue to Amelia Avenue through the Centroplex Parking Garage back to Livingston Street. Two-way bus traffic begins on Livingston Street at Garland Avenue. Heading eastbound on Livingston Street, the two-way busway operates on the north side of a two-lane roadway with two-way general use lanes. The two-way bus lane continues east on Livingston Street and turns south onto Magnolia Avenue along the west side of the roadway. A single northbound lane is provided for general traffic. The south loop of the system begins on Magnolia Avenue at Church Street. The south loop continues along Magnolia Avenue on the west side and turns right (westward) onto South Street, a three-lane, one-way westbound roadway. The loop turns northward onto Orange Avenue on the east side and runs contraflow to the three-lane, one-way southbound Orange Avenue. The loop continues north, turns right (eastward) onto Church Street, and remains on the south side of one-way traffic on Church Street back to Magnolia Avenue.

Passengers board and alight on the right side at both the bus stations and stops. Stations located along the busway traveling northbound on Magnolia Avenue and Eastbound on Livingston Street will have passengers board and alight at stations in the median.

Traffic flow and roadway geometry were necessary to implement the system and included the conversion of Magnolia Avenue between Jackson Street and Livingston Street from a two-lane bi-directional roadway to a one-lane one way roadway northbound, reduction or elimination of on-street parking, narrowing of general use lanes and additional ROW.

Station Design

The busway uses paired stations at intersections so there are both near and far side stops. A station is pictured in Figure E-2. Since the busway is an exclusive lane, traffic impacts of the stopping bus at the intersection are not a concern. The near side stops are positioned far enough back so that a dwelling bus does not actuate the busway signal loops. The stations are designed so that two buses can dwell at the far-side stations. This is necessary so that buses do not queue into the intersection.

Figure E-2: A LYMMO Station

Station boarding occurs on the right side. For buses traveling north on Magnolia Avenue and west on Livingston Street, boarding occurs in the median bus stations. Right curbside boarding is provided at all other stops and stations.

Station platforms are level with the sidewalk are provided, and they are non-skid and weather resistant for added safety. Station lengths are approximately 50 feet with varying width depending on the station location. Each station is equipped with a covered waiting area to protect from the sun and rain and a kiosk that provides information on the next LYMMO bus arrival. Each station is equipped with a sign indicating the station location such as “Church & Orange.”

Contraflow Elements

Figure E-3: Left Turn Yield Sign

A few segments of the busway run contraflow. Orange Avenue is a one-way southbound road used by general purpose traffic. The busway runs northbound contraflow on this roadway. Orange Avenue is intersected by a bank driveway just south of the stop at Church Street. Drivers entering the bank were not expecting northbound vehicles to their left which created a safety problem. Signs were installed to tell drivers to look left and yield to buses as shown in Figure E-3.

The southbound busway on Magnolia Avenue also runs contraflow to a one-way general purpose lane. In addition, the eastbound buses on Livingston Street run contraflow to two-way bi-directional general purpose traffic. Driveways along these two segments with posted stop signs have an additional sign below indicating no left turn.

Pedestrian and Bicycle Considerations

All pedestrian crossings of the busway are signalized. The system includes one mid-block crossing at the courthouse. This crossing is equipped with a signal.

Traditional pedestrian signals are used at the busway intersections. The crossing distances are very short. At the intersection at City Hall, a leading pedestrian interval (LPI) is used to provide some advance time for the pedestrian to enter the intersection.

One interviewee noted that at some of the intersections, LYMMO gets the green while parallel pedestrians are held with the DONT WALK. Because buses are not turning at these intersections, there is no need to delay the pedestrians.

When asked if bicycle lanes should be used in conjunction with a bus lane, the interviewee noted that this would be problematic. The difference in speed could reduce busway flow and introduce a potential safety problem.

Direct pedestrian channelization is not used along the busway unless there is a problem. One interviewee noted that there is a slight problem with pedestrian flow near the Post Office on Magnolia Avenue at Jefferson Street. Although a raised median with planters is provided to separate the LYMMO lanes from the general use lanes, pedestrians were observed to cross at mid-block and not at the designated crosswalks at Jefferson Street and Washington Street. The section is being monitored to see if mid-block crossings become more prevalent and will then implement steps to deter mid-block crossings.

An example of the signs used to prohibit pedestrians from crossing and encourage them to cross at the traffic signals is pictured in Figure E-4.

Figure E-4: Signs Prohibiting Pedestrians from Crossing

ADA Elements

The busway has many users who require assistance. In order to accommodate users with disabilities, a number of ADA elements were incorporated into the design include wayfinding measures, tactile warnings at the platform, sidewalks level platforms high visibility markings, and wheel chair ramps. The LYMMO buses all kneel to make boarding and alighting easier for passengers with disabilities.

One interviewee noted that there is a problem with the depth of the tactile warning. The tactile warning is provided for passengers with visual impairments. However, the depth of the tactile warning creates a problem for wheelchair users as it is difficult to travel over.

OPERATIONAL ASPECTS

All intersections along the bus route are signalized except for a stop controlled T-intersection on Wall Street at Magnolia Avenue. Buses do not stop since Wall Street traffic is one-way and restricted to right turns onto Magnolia Avenue and therefore there are no bus conflicts.

Signal Systems

The LYMMO system employs transit signals for the busway. The transit signals are illuminated white bars on a three-aspect display unit signifying Stop, Caution/Prepare and Go. An example is provided in Figure E-5. All of the downtown signals are equipped with programmable heads. Louvers are not an option due to the proximity of intersections in the downtown environment.

Figure E-5: LYMMO Bus Signal

The bus signals have a five to seven second green (vertical line), followed by a three section change period. Intersections do not have an all red phase. This timing allows two buses to progress through the intersection.

The LYMMO system has its own signal phasing. Priority is given to the busway as it helps to reduce some vehicle trips from the downtown grid.

Priority

The LYMMO buses receive priority through the use of infrastructure-based detection at the intersection. Two priority calls are allowed per cycle. This does not increase the cycle length because the signal is not pre-empted. If private vehicles enter the busway, they will also actuate the bus signal.

The downtown signals use a consistent cycle length. This is important to maintain the downtown progression. The east/west routes are progressed through the downtown grid. Similar controller timing plans are used along the Magnolia Avenue corridor. Table E-1 displays a controller timing sheet for the intersection of Magnolia Avenue at Robinson Street.

Table E-1: Controller Timing Sheet Sample

	RING 1				**RING 2**
Approach	**Late**	**E/W**	**Early**	**N/S**	**Bus**
Description	**Bus**	**Robinson**	**Bus**	**Magnolia**	**Signal**
Phase #	1	2	3	4	OVL-A
Initial	4	10	4	8	This is a Overlap "A" Standard with Phase 1 and 3
Passage	6	3	6	3	
Yellow	3	4	3	4	
Red Clear	0	1	0	1	
Max 1	7	35	7	35	
Max 2	7	45	7	23	
Walk		11		11	
Ped Clear		13		12	
Min Recall		Yes			
Max Recall				Yes	
Ped Recall				Yes	
Non-Lock	N/L	Lock	N/L	Lock	
Rest in Walk		Yes		Yes	
Display	Bus	Ball	Bus	Balls	
U.C.F.	R	Y	R	R	
Main St		Yes			
L/S Position	5	2	5	4	5

The buses are also equipped with GPS transponders. These GPS units are not used for signal priority. Instead, they are used for communication. Each LYMMO station is equipped with an ITS device that provides the real-time position of buses in the system from the GPS unit. This allows users waiting at the station to know when the next bus will arrive.

Turn Treatments at Intersections

At many of the intersections, vehicles in the parallel general purpose lanes make left turns across the busway. The vehicle phase is before the bus phase. If the bus phase was first, there is some concern that the vehicles would also move forward in response to the motion of the parallel buses. Similarly, at intersections where buses turn left, the vehicle movements precede the bus movement. However, the LYNX representative noted that in congested conditions it might be advantageous to have the bus preceded ahead of the vehicles to avoid left-turning vehicles that may queue into the intersection and block the busway. It was noted that during special events, vehicular traffic turning left into the parking garage at Amelia Avenue back up into the intersection that may impede the busway. LYNX indicated that police target enforcement is coordinated with LYNX as part of any special event planning.

Many of the busway intersections are adjacent to one-way streets. As such, the number of applicable movements is reduced. Applicable turning movements are only prohibited at intersections if there is a safety concern.

At one intersection, Orange Avenue and Jackson, left-turning vehicles must yield to northbound buses. Orange Avenue is one-way southbound at this intersection; the busway is one-way northbound. A dynamic sign is used at the intersection to instruct left-turning vehicles to yield when buses are approaching. This sign is pictured in Figure E-6.

Figure E-6: Dynamic Sign at Jackson Street and Orange Avenue

Emergency Vehicles

Emergency vehicles are allowed to use the busway when responding to an emergency. Emergency vehicles have pre-emption in the downtown system so training in the busway signals is not needed.

Unauthorized Entry

Unauthorized entry has continued to be a problem on the busway. It is especially a problem on weekends when there are more unfamiliar drivers downtown. In some sections, once vehicles enter the lanes, it is very hard for them to exit. LYNX has asked the police to target this violation. In order for it be enforceable, signs have to be posted. LYNX has asked the City traffic engineering staff to add signs to deter motorists from entering the busway and to allow police officers to enforce this violation.

The LYNX staff works closely with the police to identify unauthorized entry problems on the system. Recently, the police have been monitoring an intersection near the courthouse. The roadway is one-way southbound there. Vehicles have been using the busway lanes to go northbound. This problem was identified through a collaborative effort of the police department and LYNX staff.

Bus Operators

The LYMMO route is a desirable route for bus operators because it is a free service. The free service eliminates fare disputes that are troublesome for bus operators. Because the route is desirable, it is staffed by senior operators. However, all operators are trained on the LYMMO system and the busway signals.

Operators are instructed in the operation of the busway signal indications, and the signal operations. They are trained that the signal will detect them when they are waiting at the intersection. They receive a visual confirmation of that detection. If a passenger asks to be released at the intersection, the operator is trained not to release the passenger until the bus has progressed through to the far side of the intersection. This is after proceeding through the intersection so as not to miss the bus phase. This reduces the number of bus phases that are needed.

Bus operators are also trained to reduce bunching of buses. Bus operators notify headquarters when they are boarding or alighting wheelchair customers because of the additional time that is required. They are also trained to allow at least a four-block separation between themselves and the bus in front of them.

Bus operators are trained to operate their buses between 20 and 25 miles per hour on the LYMMO system with the exception of one segment along Orange Avenue. On Orange Avenue between South Street and Church Street, bus operators are trained to operate their buses at 10 miles per hour due to cross street traffic turning across the LYMMO lane at Jackson Street and also at the bank drive-thru north of Jackson Street.

Operators are also instructed that pedestrians have the right-of-way throughout the LYMMO system. Pedestrian crosswalks with white striped lines indicate to operators to increase their awareness of pedestrians while parallel solid lines indicate a normal crosswalk.

As part of the bus operator education, LYNX has incorporated a simple yet effective PowerPoint presentation that helps to identify every intersection and what specific issues the driver will encounter. For example on Magnolia Avenue, the presentation indicates that there is no LYMMO stop at this location but the bus operator should use caution proceeding through the intersection due a blind spot caused by a nearby building. The presentation intersection information also provides which lane the operator should use, where operators should check for pedestrian movements conflicts, location of crosswalks, mandatory stops, bus spacing/ The presentation also provides information on nearby destinations (such as City Hall, Tag Office, Courthouse, Post Office, etc.), cross street/driveway conflicts and bus speeds.

Horns and Wayside Devices

Bus operators are also trained to use their horns when backing up or in emergency situations. Horns should not be used for recurring situations such as a blind corner as their repeated use may desensitize pedestrians and vehicles to the sound. Instead, devices such as a wayside horns or advance rumble strips would be preferred.

SAFETY EXPERIENCE

The LYMMO system has had relatively few safety problems and is one of LYNX's safest routes. In the eight-year period from August 1997 through November 2005, there were only 52 vehicle/bus crashes reported on the system that included 22 crashes at intersections. The predominant crash scenario is a vehicle running the red light and hitting the bus. There are also a minimal number of conflicts at driveways. Due to the bus operators experience and training, they are able to anticipate driver confusion, and minimize the number of conflicts at driveways.

Other safety concerns arise when vehicles occasionally enter the busway lanes. This is only a concern at the segments of the busway where the general purpose lanes are separated from the busway lanes by raised pavement markings. At the median separated sections, the sight distance is good enough that if a vehicle does enter the lanes, the bus operator has enough time to react and avoid a crash.

Crashes between transit vehicles and pedestrians have been very rare on the busway. In the eight-year period of operation, there were four claims involving a bus and pedestrian (outside of the bus). It was noted that pedestrian conflicts mostly occur when passengers are boarding or alighting the buses, passengers are inside and the bus stops suddenly, or pedestrians are hit by the side mirrors. The buses operate at a very low speed (at or below 20 -25 mph) on the busway. The operators are trained to be alert for pedestrians, particularly for pedestrians running to catch the bus or for pedestrians getting off the bus.

A safety concern was identified near City Hall where the busway runs contraflow to general traffic. Pedestrians were stepping into the path of oncoming buses because they did not expect that buses would be coming from that direction. A guardrail along with signage directing pedestrians to cross at the traffic signal was installed to encourage pedestrians not to cross at that location.

PUBLIC INFORMATION CAMPAIGNS

When the system was opened, there was a lot of local and national media attention. The free local news coverage provided a venue to explain some of the new technologies of the system. Since the opening of the busway, mass media has not been needed.

The City also appointed a liaison to work with local businesses during the construction of the busway. Close cooperation with local business owners has helped to secure their support for the busway. The liaison worked with each business owner to understand their needs, minimize disruptions to their business from the construction, and provide advance notification of any disruptions.

CONSIDERATION OF OTHER TRAFFIC CONTROL DEVICES

Crossing Gates

The representatives from the City of Orlando operations staff were asked if they considered the use of crossing gates at any of the intersection. They noted that they would use gates for pedestrians if safety at a crossing became a problem.

LYNX staff was also asked if gates were an option at any of the intersections. They noted that gates might be beneficial for vehicles but not for pedestrians. Pedestrians go around most everything. They also noted that liability is a concern if the gate doesn't function correctly and it may hinder emergency vehicles. If gates are used, there should be very specific criteria that establish when a gate is needed.

Colored or Textured Pavement

One of the original ideas for the LYMMO system was to have the appearance of rough cobblestone with smooth tracks for the buses. However, there was some concern that this may limit emergency vehicle use. The resulting design has a different grade on the busway that creates a different appearance and feel than the general purpose lanes.

LYNX staff would prefer some type of color pavement if they could have it. When asked what color or texture they would prefer, responses included orange or lime; grassy green, dirt brown, or cobblestone; and brown or anything to contrast with slate grey.

Other Devices

LYNX staff suggested that a flashing light similar to a school crossing may be beneficial as a warning when buses are approaching.

FUTURE PLANS

LYNX and the City of Orlando are considering the expansion of the system to include a two-mile north/south extension to the hospitals or some east/west routes. There is also discussion of charging a nominal fee, perhaps $0.25, for the service.

ADVICE FOR OTHER AGENCIES

The interviewees were asked what advice they would provide for other agencies that are planning busways. Their suggestions included:

- Make appropriate provisions for bicyclists. Whenever possible, treat bicyclists like drivers. Additionally, provide adequate bicycle parking that is obvious, inviting, securable, and visible. If this is not provided, bicyclists may secure their bicycles to pedestrian channelization devices or to other devices that may introduce a hazard to pedestrians.
- Do not use meandering sidewalks or pedestrian routes. This may encourage pedestrians to find other routes.
- Pedestrian improvements should be integral to the design of the intersections. The busway will likely increase pedestrian volumes at the intersections.
- Escape areas are necessary for breakdowns or emergencies.

APPENDIX F
SOUTH MIAMI-DADE BUSWAY

INTRODUCTION

The South Miami-Dade Busway is an exclusive, two-lane, two-way transit facility generally located parallel to US-1 in Miami-Dade County. The first phase, Phase I, of the Busway opened in 1997. This 8.2-mile long segment was constructed by the Florida Department of Transportation and turned over to Miami-Dade County for subsequent operation. It extends from the Dadeland South Metrorail Station in the north to SW 112 Avenue. The facility connects the fast-growing suburban and more agricultural areas of south Miami-Dade County with the Dade-South Metrorail station located approximately 10 miles south of downtown Miami. The Busway is built in an abandoned Florida East Coast rail right-of-way.

Phase II is being constructed in two segments. Segment 1 opened on April 25, 2005 and extends from SW 112 Avenue to SW 264 Street. This is the northern segment of Phase II and adds another 5.5 miles to the Busway. Construction on Segment 2 of the Busway, the final 6.3 miles segment, started in the fall of 2005. It will extend from SW 264 Street south to SW 344th Street. When complete, the entire Busway will be 20 miles long. The Busway is shown in Figure F-1.

The Busway has two lanes each 12-feet wide separated by a 4-foot wide painted centerline. There is also a 10-foot wide pedestrian and bicycle path within the Busway right-of-way to the west of the bus lanes. The Busway occupies a 100-foot right-of-way.

The parallel roadway, US-1, is a heavily traveled six-lane divided arterial that carries over 90,000 vehicles a day. This corridor is heavily congested, with many intersections operating at or near capacity during peak hours. There are heavy turning movements to and from east-west streets, with multi-phase traffic signal operations. The distance between US-1 and the Busway varies from as close as 50 feet in the northern sections to 400 feet in the southern sections.

Eight different bus routes use the Busway. They include Routes 1, 31 (Busway Local), 34 (Busway Flyer), 38 (Busway MAX), 52, 65, 252 (Coral Way MAX), and 287 (Saga Bay MAX). Some of the routes travel the full length of the Busway, while others use the corridor for part of their route as they also travel through adjacent communities. An express route, the 34 (Busway Flyer), offers service that stops at only five of the 15 stations. Three sizes of buses, including 29-foot minibuses, 40-foot standard transit coaches, and 60-foot articulated vehicles use the facility. All of the buses using the Busway are powered by standard diesel engines. Most buses on the Busway have low floors. Given the mixture of transit services offered on the Busway, there are as many as 30 buses an hour during the peak hours (6 a.m. to 9 a.m. and 3:30 p.m. to 6:30 p.m.) in one direction on the northern portion of the facility, while the frequency of service reduces to 16 buses per hour in the middle of the day.

The project team met with representatives from the Florida Department of Transportation including Rory Santana; Miami-Dade Transit including David Fialkoff, Isabel Padron, Albert Hernandez, Eric Muntan, and Derrick Gordon; and Miami-Dade County Works including Bob Williams and staff.

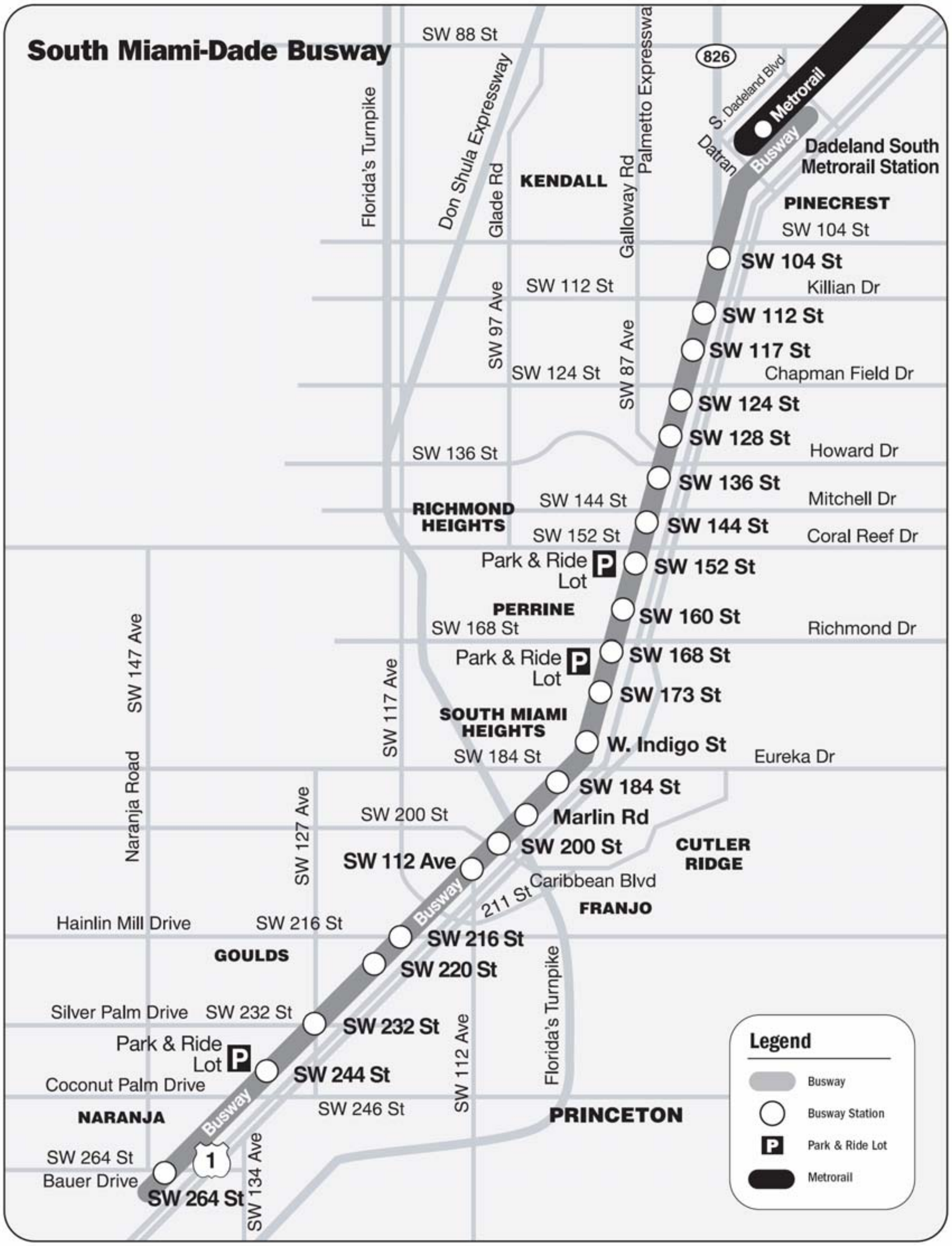


Figure F-1: South Miami-Dade Busway
(*Source: Miami-Dade County, Transit, South Miami-Dade Busway website,*
http://www.miamidade.gov/transit/south_miamidade_Busway.asp. Extracted March 14, 2006.)

DESIGN

General Intersection Design

The Busway intersections can be classified into two types: closely-spaced and isolated. The closely-spaced intersections are those that are immediately adjacent to US-1, or another parallel arterial. The intersections of the cross street and the parallel arterial and the cross street and the busway operate together as one intersection. An example of this is provided in Figure F-2. The isolated intersections are those that are separated from US-1 and operate as an entirely separate intersection. Most intersections are signalized, although some are stop-controlled. Vehicles are allowed to queue between the Busway intersection and the US-1 intersection at the isolated locations. An example is provided in Figure F-3.

In the section of Busway constructed during Phase I, there is a very clear distinction between the two types of intersections. The closely-spaced intersections are located immediately next to US-1 and the isolated intersections are separated by a distance of approximately 400 feet to the west of US 1. In the second phase of the Busway, the distance between intersections varies. Therefore, a distance criterion was developed by the highway designers to differentiate between the two. Intersections that are less than 100 feet away are considered closely-spaced and intersections over 100 feet away are considered isolated.

As illustrated in Figure F-2, the US-1 intersections generally have two to three through travel lanes in each direction divided by a median, a left-turn bay for northbound left-turns, a right-turn bay for southbound right-turns, and if needed, a left-turn bay for southbound left-turns or a right-turn bay for northbound right-turns. The Busway has one lane in each direction. The length of the bays and the distance between the Busway and US-1 varies by intersection. Vehicles are not allowed to store between the Busway and US-1 to avoid queues backing up over the intersection at the closely spaced intersections, although some vehicles do. As such there are pavement markings including stop lines for eastbound cross street traffic.

According to the geometric design staff, the intersection designs were modified in Phase II based on the safety experiences of the Busway in Phase I. Elements were added to the intersections to increase the conspicuity of the intersections including the addition of curbing at the intersections, small median approach islands, and pedestal mounted signals.

Transit Stop Placement

In the Phase I segments of the Busway, bus stops are placed both near and far-side depending on the intersection geometry. According to the Miami Dade Transit representative, in the design of Phase I, in most cases the stops were placed at the locations where the busiest bus stops were located when the buses operated on US-1. There was also an effort to keep the stops 1/2 mile apart so that the maximum walking distance along US-1 to a Busway stop was 1/4 mile (approximately 1300 feet).

In Phase II, all of the stops except for two were placed on the near side in the interest of safety. According to David Falkoff, near-side stops are beneficial to passengers who have navigation difficulties because the distance from the intersection to the front door of the bus for

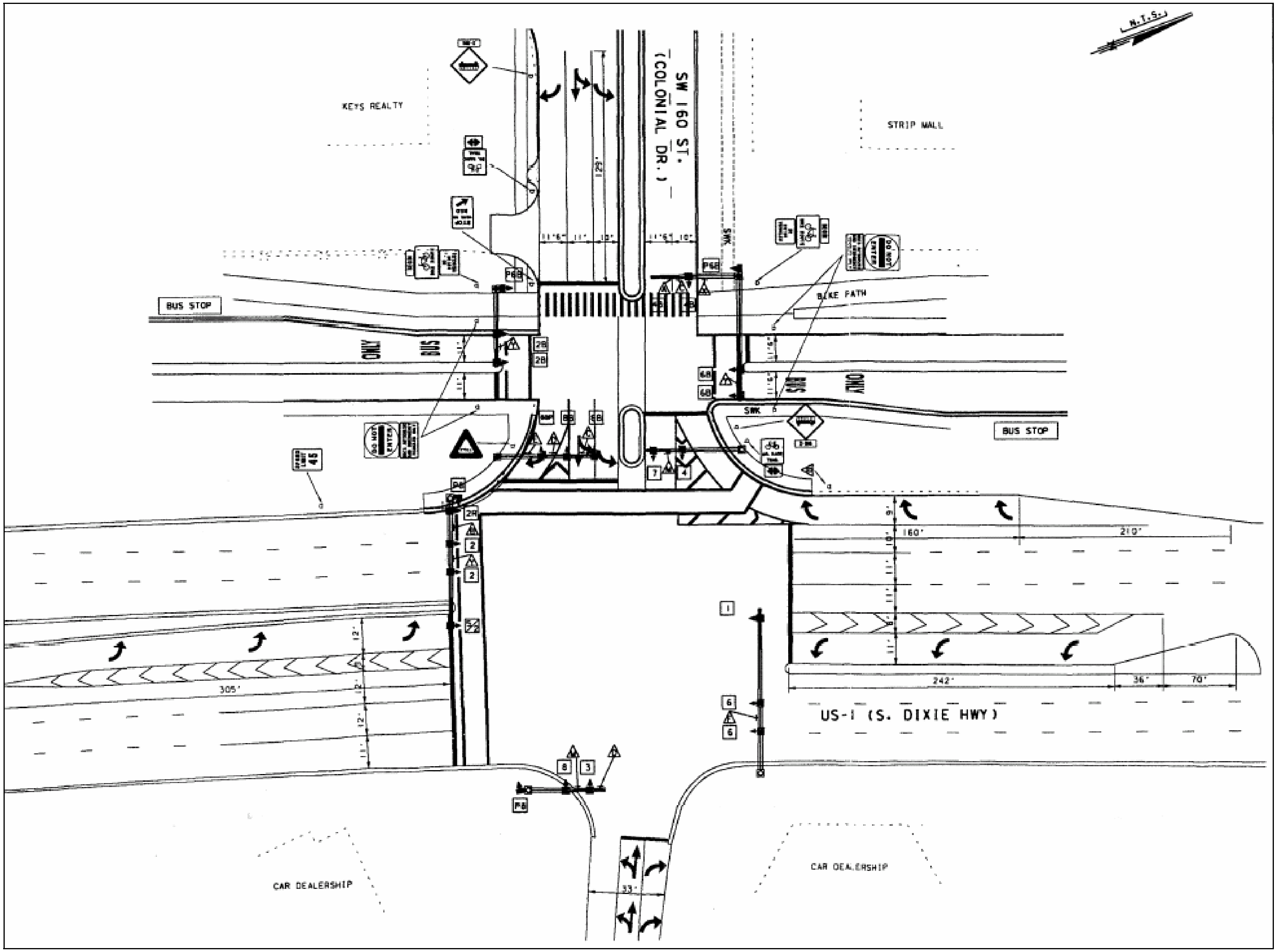


Figure F-2: Example Intersection Design for a Closely-Spaced Intersection on Busway
(Source: Condition Diagram provided by Miami-Dade Transit for SW 160 Street @ Busway & US-1)

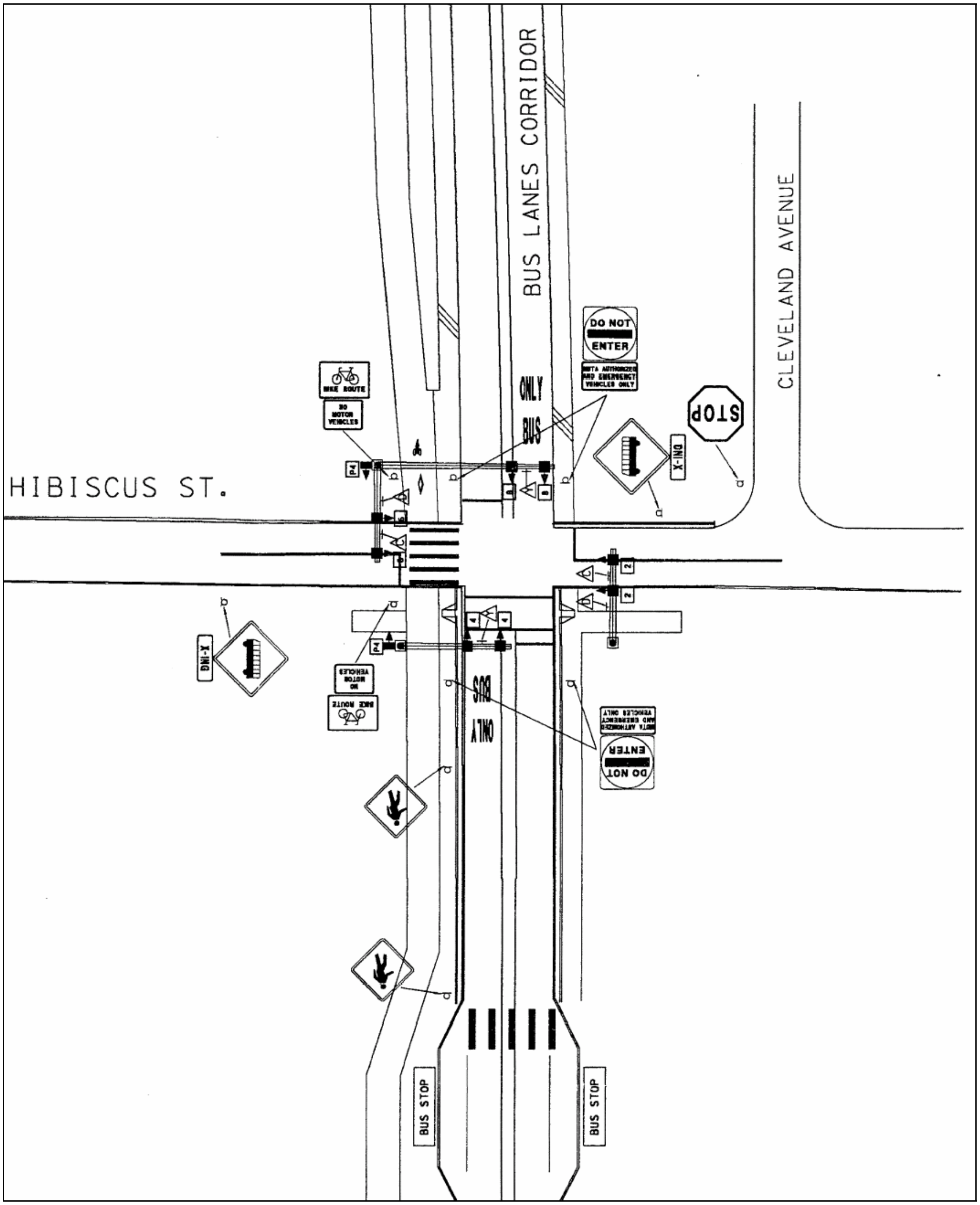


Figure F-3: Example Intersection Design for an Isolated Busway Intersection
(Source: Condition Diagram provided by Miami-Dade Transit for Hibiscus Street and Busway)

near-side stops than far-side stops. Based on interviews with the bus operations staff (further detail provided in the Bus Operating Procedures section), near side stops make the drivers stop prior to the intersection. With far side stops, the driver's focus may be downstream at the bus stop instead of on the intersection.

Pedestrian and Bicycle Facilities Design

Within the Busway right-of-way, a ten-foot wide pedestrian and bicycle path is located to the west of the Busway. The SB station stops are placed between the bus roadway and the path. The path is marked with diamond pavement markings and a supplement message that reads "BIKE PATH" on the approaches. Across the minor street approach, the path is a zebra striped crosswalk. (The MUTCD 2003 Edition Chapter 3 Section 3B.22, states that a bicycle symbol or the word BIKE LANE shall be used for a bike lane and white lines formed in a diamond shape symbol or the words HOV for an HOV lane).

INTERSECTION OPERATIONS

Intersection Control

In Phase I, all of the intersections are signal-controlled. In Phase II, there will be a few stop controlled intersections. The stop sign will face the cross street vehicle traffic. The stop signs at these intersections may be equipped with red flashers that will be activated when the bus is approaching. (It is unclear if this is allowed in the MUTCD). An example of the general design of stop controlled isolated intersections in Phase II is presented in Figure F-4.

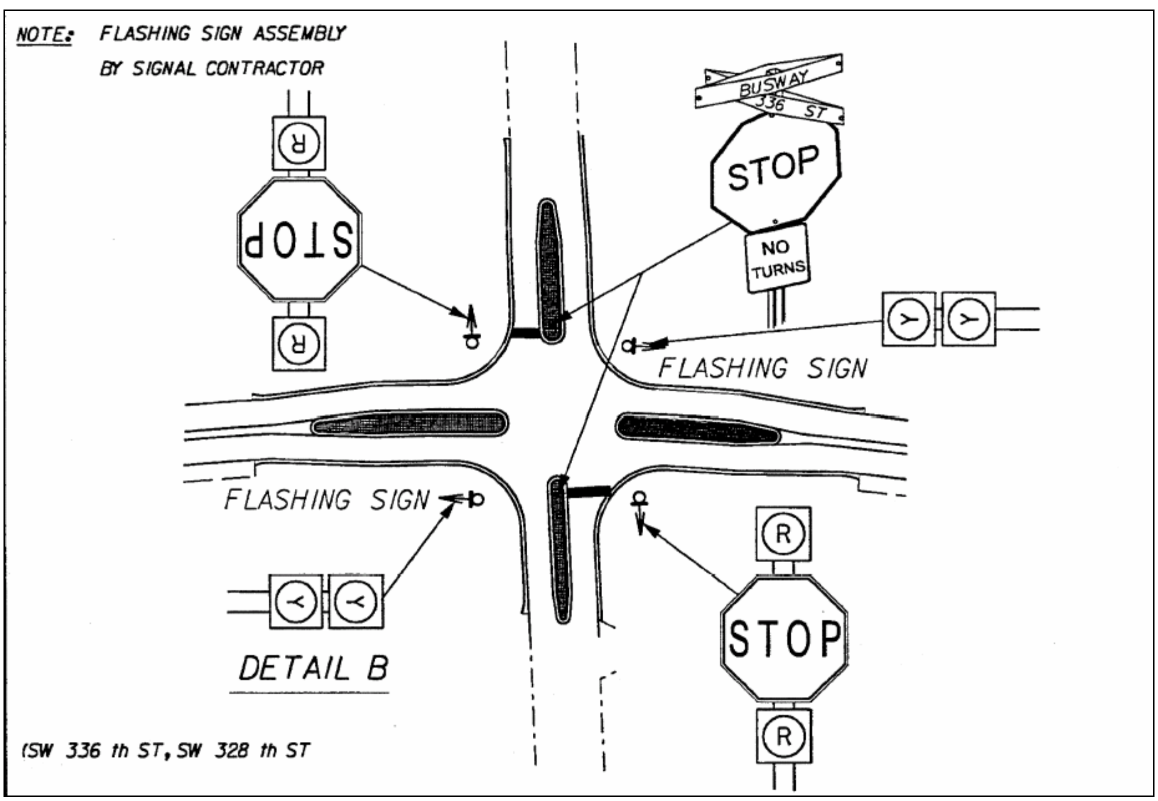


Figure F-4: Example Design for a Stop-Controlled, Isolated Intersection in Phase II

Signals

Signal Hardware and Configuration

The Busway uses standard red-yellow-green traffic signals. The project team did not consider light rail transit signals because they were not in the MUTCD at the time the system was designed. Since that time, the MUTCD has incorporated special transit signals. However, the signal displays along the Busway have not been updated to these signals and there are no plans to do so.

Where necessary, the signals have programmable heads so that their green indications can not be viewed by traffic at an upstream stopbar along US-1. The signal engineers noted that louvers would not work with closely spaced intersections.

Horizontally aligned signals are used in Miami-Dade County for both vehicle signals and the bus signals. As part of some safety improvements, supplemental pedestal mounted signals were installed at some intersections.

Signal Indications for Buses and Other Vehicles on the Busway

The Busway signals display standard green, yellow, and red balls. Green through arrows are not used because turn movements are allowed from the Busway.

The vehicle left-turn signals from the parallel arterial use green, yellow, and red arrows for lefts. The signals for the through movements display standard green, yellow, and red balls. For right-turns, a green arrow, yellow arrow, and red arrow are used.

Signal Operations

US-1 is a major arterial and its intersections govern the signal timing for the closely-spaced Busway intersections. The intersection operations at most of the signals along the corridor is as follows:

- NB US-1 left-turns are allowed at the signalized intersections during a protected-only phase. Left-turning vehicles execute their turn in a protected, leading left-turn phase. The signal display is a green left-turn arrow.
- Southbound right-turns have a separate phase that occurs during the mainline through phase. It is truncated if a bus actuates the loop.
- The Busway through phase is concurrent with the adjacent intersection's parallel through phase but is only displayed when actuated by a bus.
- Some buses make turns on to and off the Busway at intersections.
- The minor streets always operate in split phasing at US-1. That is, each minor street direction goes during its own phase.

Warranting of Signals

Since there is currently no warrant specifically for when Busway intersections should be signalized, one of the concerns with the Busway is the placement of signals where signalization is not warranted based on traffic volumes. Therefore, the Florida Department of Transportation has developed a position for Busway signalization that would impact any state road operation as follows that intersections should meet signal warrants based on vehicle delay at the intersection.

At isolated intersections where signalization is not warranted, the State DOT believes that signalization may be unexpected by motorists and may create an unsafe situation.

The Florida Department of Transportation District Traffic Operations Engineer noted that approval for signals was not given by the County Public Works Department. Meeting the warrants is not an absolute requirement for the Department; they are willing to incur vehicle delay for transit safety and efficiency if adequate support is provided.

The county signal engineer also believes that signalization should be considered in relation to MUTCD warrants. There was some discussion that a Busway signal warrant could be developed based on the number of people affected instead of the number of vehicles affected. Because of their much higher occupancy (30 to 40 passengers per vehicle), the person delay is much higher with a traffic signal. A proposal for this warrant was presented to the NCUTCD but a warrant was not developed.

In Phase I of the Busway, the six isolated intersections do not appear to meet conventional traffic signal warrants. These intersections have been a source of right angle crashes.

Signal Failure Mode

During signal failure mode, the Busway receives a flashing red at the intersections closely-spaced with US-1. At the isolated intersections, the Busway also receives a flashing red while the cross street receives a flashing yellow.

Signal Priority

Transit Signal Priority

The signals along the US-1 corridor employ a 160-second cycle length at many times of day. About one-half of the cycle is given to A-phase. Currently, the Busway signals only use actuation at the signal. That is, if a bus arrives at the intersection during the mainline (US-1) through movement and there is enough time remaining, the Busway will receive a green display. The green phase will occur after the right-turn phase and clearance interval is ended. It is approximately 12 seconds before the bus receives the green if they arrive at the start of the right-turn phase. This accounts for the right-turn green, yellow, and the all-red interval. It varies depending on the distance from US-1 to the Busway intersection. That is, the all-red needed for the right-turning vehicle to clear the Busway intersection is longer when the intersections are further apart. Bus actuation is not acknowledged at the end of the green for the major movement. Therefore, the east/west minor movement does not get held longer in any scenario.

As designed, the system could prepare for this Busway green phase in advance of the bus arriving through the use of advance actuation. However, the advance actuation loops were disabled in response to safety concerns and may be reinstated after all of the safety measures are in place. A 2001 study (*1*)found that crashes were more likely when the advance loop detectors were activated. This confirmed the suspicions of the Florida DOT District Traffic Operations Engineer. This is likely correlated to the difference in bus travel speed through the intersection with activation as opposed to without activation. When the loop detectors were activated, buses were able to receive a green signal and proceed through the intersection at a speed of 45 m.p.h. The results of this study are further discussed in the section on Phase I safety.

As it is currently operates, the bus has to wait approximately 12 seconds even if it arrives during the appropriate interval and longer if it arrives during the minor street movement, the left-turn phases, or at the end of the major street green.

Emergency Vehicles

Emergency vehicles are allowed on the Busway. According to the transit agencies, enforcement officers are encouraged to use the Busway even in non-emergency mode to provide visual deterrents to crime on the Busway. The original approval for the Busway only allowed operation of emergency vehicles on emergency runs. By allowing all emergency vehicles to use the Busway, it has created additional delay for buses, regular street traffic and emergency vehicles that are on emergency runs by affecting the signal operations with extra priority calls and recovery cycles.

Vehicle Signs and Pavement Markings

Signs and Pavement Markings to Deter Unauthorized Entry

There are numerous signs and pavement markings to deter unauthorized entry at the Busway intersections and generally include the following:

- BUS ONLY pavement markings on the Busway approaches;
- Dual DO NOT ENTER signs on the Busway approaches that are equipped with supplementary plaques that indicate MDTA authorized and emergency vehicles are allowed;
- Overhead roadway signs that identify the facility as “BUSWAY”; and
- Graphical advance Busway crossing signs on the minor street approaches.

Colored Pavement

The Busway does not employ any type of colored pavement. However, interviewed staff noted that colored pavement would be a good addition to the system although cost prohibitive. When asked about the color of pavement that would be used if the Busway employed colored pavement, the state district operations engineer responded that coral or another color that is currently not assigned should be used.

Right-turn on Red Prohibition

Right-turns on red are strictly prohibited from the southbound mainline because of the danger of turning into the path of an oncoming bus. The potential conflicts between these right-turning vehicles and the Busway were identified after numerous crashes occurred and measures were taken to increase the visibility of the prohibition. A double red arrow is used for the right-turn combined with advance signs to communicate the prohibition. Blank out signs were not considered at these intersections. Right-turn on red is also prohibited from the eastbound side street onto southbound US-1. According to the Miami-Dade Transit representative, this was a major issue when the Busway opened, and was solved by allowing this movement, on green arrow, during the westbound minor street movement.

Pedestrians and Non-Motorized Users

All intersections are equipped with traditional pedestrian signals. Pedestrian countdown signals are employed elsewhere in the county and will eventually be employed county-wide, including at the Busway intersections.

The pedestrian phases at the Busway intersections are concurrent with the parallel vehicle phases.

One intersection, 144th Street, is equipped with an audible pedestrian signal. The signal provides a locator tone for pedestrians with visual impairments to locate the pedestrian signal actuation button. The tone accelerates during the pedestrian crossing phase.

Gating to Deter Unauthorized Entry

Unauthorized entry is deterred through the use of conventional pavement markings and signs. The Florida Department of Transportation District Traffic Operations Engineer was asked about the possibility of using gates at the Busway intersections. He noted that there were multiple operational problems with using gates. Namely, the gate placement would be problematic, particularly at the closely-spaced intersections. At these intersections, right-turning vehicles are the predominant safety problem. Gates could not be placed effectively to reduce right-turn on red violations. A second problem with gates is the loss of time from the signal cycle that would be needed to lower the gates from the approaching bus and then raise the gates after the bus cleared the intersection. This loss of time would affect both bus and vehicle operations.

The county signal engineer similarly did not like gates because they are expensive and there are many concerns about the maintenance of the arms.

Gates were considered in the original design of the busway. However, they were deemed impractical due to the frequency of crossings, among other issues.

IMPACT ON SURROUNDING NETWORK

Northbound left-turns were changed to protected left-turns at all closely-spaced intersections along U.S 1. This reduces the capacity of the intersections. In many cases, there were no funds available to increase the turn bay lengths to accommodate the longer queues. Therefore the queues often spillover into the through lanes. This has created a congestion problem in the intersection.

When the Busway was installed, the side streets had to become split phased to avoid vehicles, particularly left-turning vehicles, backing up over the Busway. This split phasing also reduced intersection capacity by increasing the number of phases and adding to the lost time in the cycle. Some minor streets approaches were widened at the intersection; at most intersections, they were not widened on the approach because there was no funding to permit the purchase of additional right-of-way for the minor streets. Therefore, the throughput of the intersection is limited by the width of the approach lanes. This can cause additional delay for minor street vehicles.

The State DOT noted that to accommodate more buses per hour and provide truly express service, the use of non-transit or non-active emergency responders should be reduced or eliminated. Every vehicle that travels on the Busway and triggers the signal causes some disruption of operations to the Busway and surrounding road network. By reducing or eliminating the number of these unnecessary activations, the entire network will benefit.

At one intersection in particular, Marlin Road, a problem was identified with the isolated intersection and the US-1 intersection. Although there is 400 feet between the isolated intersection of the Busway and Marlin Road and the intersection of US-1 and Marlin Road, the queue on Marlin Road from US-1 would back up over the Busway intersection due to very heavy traffic volumes.

BUS OPERATING PROCEDURES

The number of crashes along the Busway, particularly crashes associated with right-turn on red, have decreased since the start of the Busway operations. According to the operations staff, vehicles from US-1 are still violating the right-turn on red prohibition. However, the bus operators are trained to anticipate this problem. This training has likely resulted in decreased crashes.

Bus operators, operations, and maintenance employees are provided with the following standard operating procedure for approaching intersections on the Busway alignment:

- Place foot on brake pedal.
- When approaching all Busway intersections, decrease speed to no more than 15 MPH. This includes buses traveling on the Busway, entering the Busway, and buses crossing the roads that intersect the Busway.
- Check traffic first left then right then left again.
- Proceed through the intersection when clear [and the signal is green].

This guidance was initiated on November 1, 2000 and has been in place since then. This procedure may be repealed after all of the safety improvements are implemented.

When the new section of Busway opened in April 2005, operations employees were again reminded that caution should be exercised at all intersections along the Busway and that in the new extension, some of the intersections are regulated by stop signs instead of traffic signals. Since they now have some stop signs along the route, the intersection crossing guidance was expanded to include that they should come to a full and complete stop at Busway intersections that are controlled by a stop sign. Additionally, they were notified of some safety concerns including:

- Vehicles turning right from southbound US-1 heading westbound cross the Busway without stopping.
- At three intersections, there are no stop signs or signals that would require westbound vehicles to stop before crossing the Busway.
- There is a short distance between the Busway and US-1 at some intersections allowing vehicles to cross the Busway immediately after turning right from southbound US-1.

All Busway operators are trained on the actual Busway route during their training.

The bus operations staff interviewed indicated that they prefer near side stops for safety. The near side stops make the drivers stop prior to the intersection. With far side stops, the driver's focus may be downstream at the bus stop instead of on the intersection.

When asked if buses should have louder or train sounding horns, the bus operating representatives indicated that they should not and in fact should only use their horn when absolutely necessary. They noted that the horn is used for emergency situations and may scare pedestrians.

Bus operators have a transit service improvement form they can use if they identify a safety problem. This form is filled out and submitted to a Lead Bus Supervisor.

SAFETY

Crash History

Since the Busway inception in 1997, there have been 106 reported crashes on the Busway and involving transit vehicles. Approximately 200 injuries and five fatalities were reported in the eight-year period. The entire transit system has approximately three to six fatalities a year.

Phase I Safety

According to the safety office, some of the safety problems experienced in the first segment of the Busway were a result of the drastic change in traffic patterns at the intersection. People were not accustomed to the drastic change in traffic patterns. From February 1997 to November 2000, 67 crashes that involved buses were recorded at Busway intersections, 49 involved injuries and two resulted in fatalities.

When the Busway first began operation, there were two predominant crash types. The first were at closely-spaced intersections. Vehicles violating the right-turn on red prohibition crashed into the buses immediately after their turning maneuver. The second type of crash occurring at isolated intersections. Vehicle drivers who violated the traffic signal would crash with the bus. The drivers of these vehicles may have failed to notice the traffic signal at the intersection.

A consultant was hired to analyze the safety of the Busway and a report was finalized in August of 2001 (*1*). The study found that a greater likelihood (seven times) of crashes existed at the isolated Busway intersections than at the closely-spaced intersections. The study also found that crashes were more likely when the advance loop detectors were activated. This is likely correlated to the difference in bus travel speed through the intersection with activation as opposed to without activation. When the loop detectors were activated, buses were able to receive a green signal and proceed through the intersection at a speed of 45 m.p.h.

At the closely-spaced intersections, a high number of crashes were the result of right-turn on red violations.

The report identified short, medium, and long-term solutions. Many of the short-term improvements have been implemented since the report was published and include:

- Modify the advanced loop operations for a bus approach speed of 15 m.p.h.;
- Modify the placement of advanced loop detectors installed at near side bus stops (to avoid unnecessary activation);
- Install additional Busway Crossing Warning signs; and

- Remove overgrown vegetation.

The following short-term recommendations were made for isolated Busway intersections:

- Install post mounted signals with STOP HERE ON RED signs;
- Install backplates to the signal heads for eastbound and westbound approaches;
- Install raised curbs on the corners of the intersections;
- Install Busway Signal Ahead signs; and
- Program downstream green displays to not be visible at upstream stopbars.

Similarly, the following short-term recommendations were made for closely-spaced Busway intersections:

- Install post mounted signals for southbound right-turns from US-1 with supplemental right-turn on red prohibition signs;
- Install large (30" by 48") right-turn on red prohibition signs; and
- Remove unnecessary RIGHT LANE MUST TURN RIGHT signs on US-1.

Medium-term recommendations for both intersection types included:

- Install a raised central island on side street approaches of isolated intersections;
- Install a textured road surface at isolated Busway intersections; and
- Install in-roadway amber-red lights (not yet approved by the FHWA).

Long-term recommendations for both intersection types included:

- Install flashing signals, similar to those used for railroad crossings;
- Install automatic gates, similar to those used for railroad crossings;
- Install flashing signals, similar to those used for moveable bridges; and
- Install grade separated intersections.

The upstream bus detectors for the Busway were disabled temporarily as part of the safety improvements. They will be reinstated after the safety improvements are made.

Currently, bus operators are required to decrease their speed to 15 mph when crossing intersections on the Busway. The upstream pavement loops may be modified so that they are timed to provide the green signal to vehicles that approach the intersection at 15 mph and the red signal to vehicles that approach faster than 15 mph.

Phase II Safety

The safety experiences of Phase I affected some of the design decisions in Phase II. Design improvements made in Phase II as recommended in the consultants report on Phase I included the addition of pedestal-mounted signals, the use of curb and gutter at isolated intersections to increase the visual queues of the presence of an intersection, signage to buses that they have to slow to 15 mph at intersections, and larger right-turn on red prohibition signs.

The design engineers wanted to use a turn prohibition sign that included a picture of a red arrow but the sign is not allowed in the MUTCD so they use the word version.

This section of the Busway recently opened and the safety experience to date is limited.

Identifying Safety Problems

The safety office maintains incident reports for all incidents along the Busway that involve a Miami-Dade transit vehicle.

A joint safety committee reviewed every intersection in the new alignment prior to the opening. The committee was composed of 12 individuals from different disciplines including the safety office, design office, bus supervisors, and representative from the bus operators union. Identified safety concerns were either mitigated or included in the training for bus operators.

Pedestrian Safety

Generally, there have been very few incidents involving pedestrians. There is a problem with pedestrians walking in front of the buses. However, this problem is present throughout the county and is not unique to the Busway.

Barriers have been installed along the Busway to channelize pedestrians to cross at the designated areas. Specifically, there is fencing along the west side of the Busway to keep people from entering the Busway. There is also a large swale that is a physical deterrent. In the first phase, the swale was only on the west side of the Busway. In the second phase, it will be on both sides of the Busway.

Bicycle Safety

Although there is a 10’ wide bicycle and pedestrian path adjacent to the Busway that can be used by bicyclists, many bicyclists ride on the Busway instead of the path. That has caused two recent crashes and is a concern of the Busway operations staff. They asked bicyclists why they were not using the path but instead using the Busway. The bicyclists commented that the path was “too lumpy”. Tree roots along the path have disturbed the pavement. Therefore, the bus operations staff recommend that a better bicycle path should be built to encourage bicyclists to ride on the path instead of on the Busway.

Additional Safety Treatments

The safety staff were asked about safety treatments they have considered or would like to see used but are not currently used along the Busway. They identified two treatments: crossing gates and advance rumble strips. However, they noted that the maintenance of both of these treatments would be problematic. Additionally, the safety staff noted that gates are probably not practical citing that the time available to get the gates down and up would be a concern and the gates would likely generate complaints from the public. If gates were used, four quadrant gates would be needed as vehicles will try to go around them.

When asked about the color of pavement that would be used if the Busway employed colored pavement, the state district operations engineer responded that coral or another color that is currently not assigned should be used.

GAPS IN THE MUTCD

Engineering design and operations interviewees were asked if they found any gaps in the MUTCD while designing or operating the Busway. The state district engineer noted that the MUTCD would benefit from an overhead sign for bus crossings. The design engineers noted that they would like to see an entire chapter devoted to Busway design.

EDUCATION

The Busway staff have employed a variety of public education and information campaigns. They have hosted town meetings, distribute a project newsletter, and have a project website devoted to public information.

LESSONS LEARNED

The following summarizes some of the lessons that the interviewees noted they would do differently, given their current knowledge:

- Bicycles on the Busway are problematic. Ensure that the bicycle path is well designed so that more bicyclists use it instead of the Busway.
- Increase the conspicuity of isolated intersections through the use of side mounted pedestal signals, small islands at the intersection, colored pavement on the Busway, or colored crosswalks.
- Lengthen and widen storage for minor street approaches, all lanes, to increase throughput at signals.
- Use priority systems that communicate with the approaching bus because there are different types of buses that operate on the Busway (e.g., express buses) and their priority needs are different.
- Employ indirect left-turns (e.g., Michigan lefts) at congested intersections.

REFERENCES

1. South Miami Dade Busway Safety Study, Final Report, August 13, 2001. Prepared by DMJM+Harris and R. Aleman & Associates, Inc. for Miami-Dade Transit.

APPENDIX G
RICHMOND 98 B-LINE BUSWAY

INTRODUCTION

The #98 B-Line is a bus rapid transit service that connects downtown Vancouver, neighboring Richmond, and the Vancouver International Airport along a 10-mile route (16 km). The route is composed of a variety of different running way types including 1.4 miles of separated median busway. This separated median busway is the subject of this case study. Full service commenced in the summer of 2001.

The project team visited the Vancouver and Richmond area in late September 2005 to conduct the case study visit. The team met with representatives of TransLink, the City of Richmond, the Coast Mountain Bus Company, and system bus drivers. TransLink is the Greater Vancouver Transportation Authority that is responsible for coordination of transportation in the region. The City of Richmond is responsible for the intersections operations and maintenance along the busway corridor. The Coast Mountain Bus Company operates the buses along the route.

The project team was not able to meet in person with representatives of the Insurance Corporation of British Columbia (ICBC) during the site visit. ICBC is responsible for maintaining crash data along the corridor. The project team submitted a request to ICBC for crash data after the case study visit.

The dedicated busway portion of the 98 B system is in Richmond along the No. 3 Road. It extends from Ackroyd Street in the south 1.4 miles north to Sea Island Way. Service began along this route in August 2001. The 98 B-Line Route is shown in Figure G-1. The route carries over 18,000 boardings daily.

Service operates at 5-minute headways in peak periods, 7-minute headways in the off peak, and 15-minute headways during evenings and on weekends. During peak periods, the average operating speed is 14 mph. All B-Line buses are 60-foot, diesel powered, articulated, low-floor buses.

Only 98 B line buses are allowed in the busway. The busway is also used by emergency vehicles, transit supervisors, and dedicated busway maintenance vehicles. Bicycles are not permitted to use the busway because of concerns about safety given the differential size of the bicycles and the buses that operate in the busway. During the field visit one bicycle rider was observed on the busway.

DESIGN

General Design

Figure G-2 displays a typical intersection along the 98 B Busway. The intersection of No. 3 Road and Alderbridge is pictured.

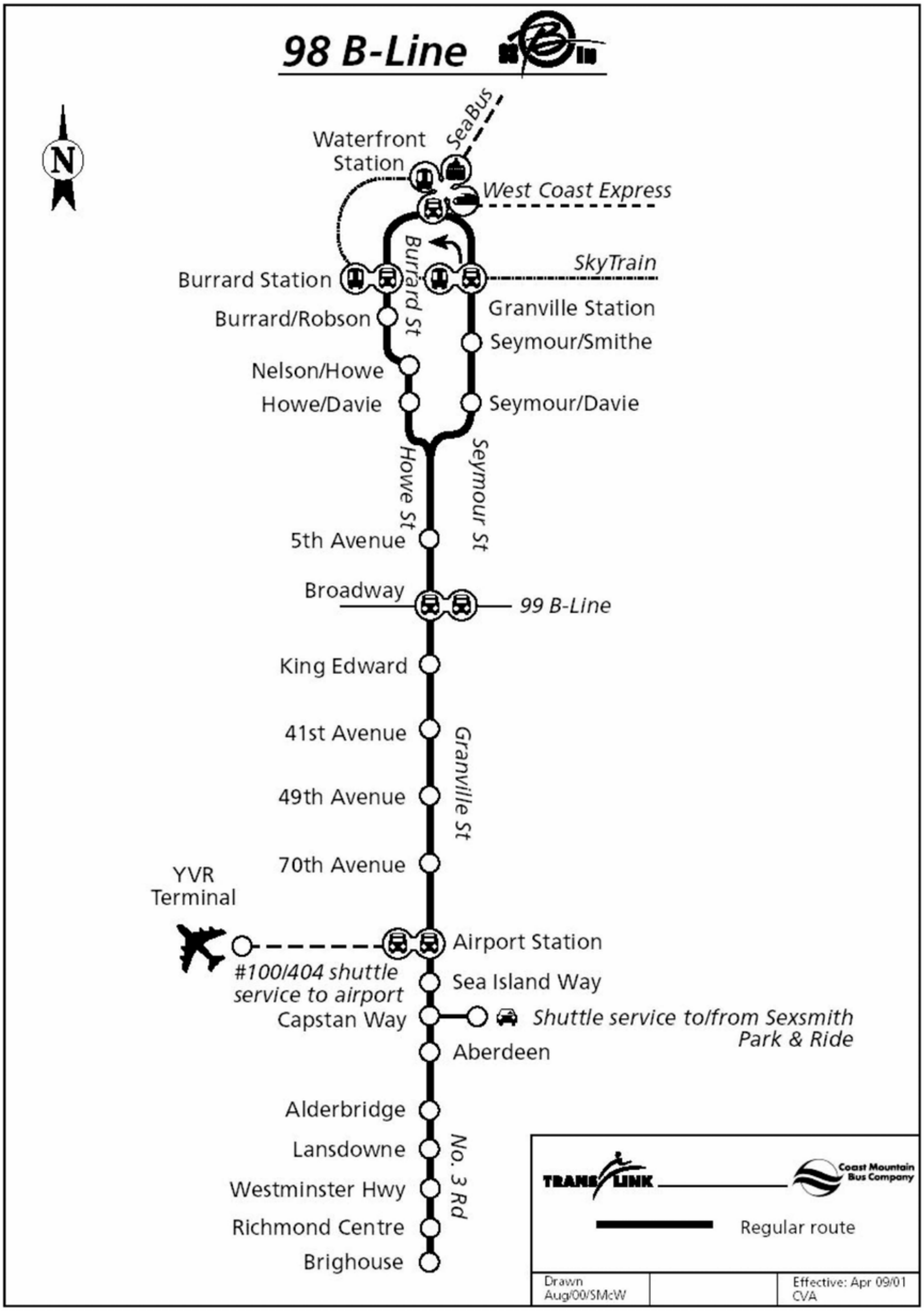


Figure G-1: 98 B-Line Route

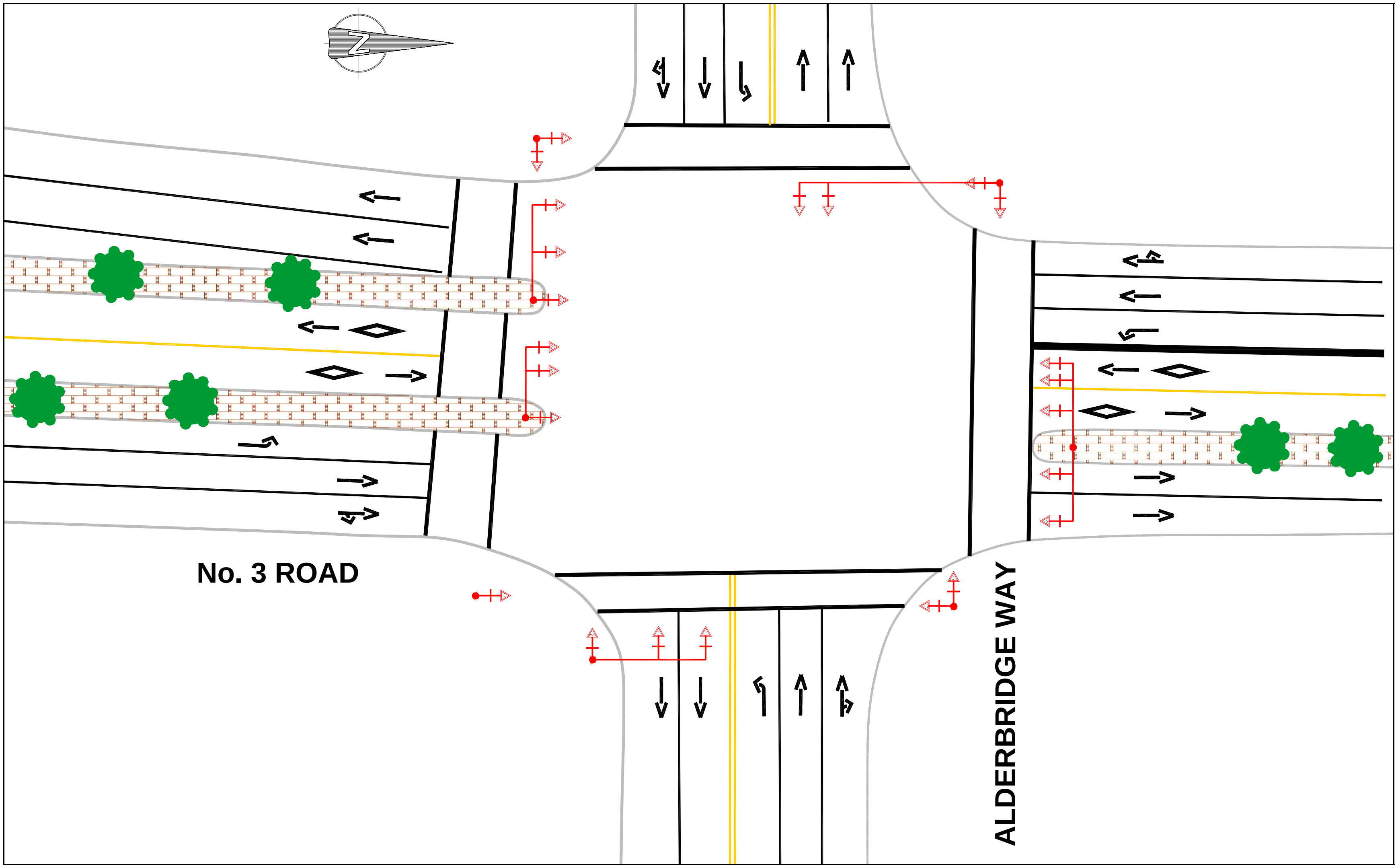


Figure G-2: Example Intersection Configuration for 98 B Busway
(Source: Based on Schematic Provided by City of Richmond)

The No. 3 Road originally had a five-lane cross-section with two lanes of through traffic in both directions and a center two-way left turn lane. The roadway had many access points along the segment. To install the busways, the general purpose lanes were narrowed and right-of-way was taken from the roadsides.

The busway is separated from general traffic by raised medians in most sections of the busway. However, at many intersection approaches, the busway separation from the general purpose traffic is only denoted by pavement markings. This occurs on the approaches to intersections where there is not sufficient right of way to provide both a left turn lane and a raised median of sufficient width to physically separate the busway. The interviewed staff noted that they would strongly prefer physical separation along the entire length of the busway, but this was not possible at most intersections. An example of a section separated by pavement markings on the approach is presented in Figure G-3.

Figure G-3: Example of Painted Separation between Busway and General Purpose Traffic on Capstan Way Intersection Approach

The agency staff were asked if they considered any other forms of separation at these locations. The staff noted they considered installing flexible barriers, likely posts made of tubing, placed at regular intervals at the intersection. However, they were concerned about the maintenance needed for these devices.

Other than the separation, most intersections employ the same design:

- One dedicated through lane for general purpose traffic and one shared through lane and right turn lane for each approach in each direction;
- A left turn bay in each direction;

- One dedicated busway through lane in each direction; and
- Painted pedestrian crosswalks.

Busway Stops

The busway has both near side and far side stops. The placement of the stops at intersections largely depends on the available right of way. Northbound, there are five stops along the busway. Southbound there are four stops. Table G-1 presents the stops and intersections along the dedicated busway.

Table G-1: Busway Stops and Intersections along 98 B Median Busway

Signalized Intersection	Northbound	Southbound
Northbound starting point at Ackroyd	---	---
Lansdowne Road	Far side	Near side
Lansdowne Plaza Signal	No stops	No stops
Alderbridge Road	Near side	Far side
Leslie Road	None	None
South end of Aberdeen Shopping plaza	Far side	---
Cambie Road	---	Far side
Yaohan Shopping Center	No stops	No stops
Capstan Way	Far side	Far side
Sea Island Way	Far side	---

Channelization of Pedestrians

Passengers load and unload at bus stops along the right side of the median busway. As a result, the intersections at which bus stops are located have high pedestrian volumes. Pedestrians are channelized to cross at the traffic signals through the use of decorative fencing and landscaping. Figure G-4 provides an example of this at the Capstan Way northbound stop. The area leading to the station is channelized with decorative fencing. The pedestrians are deterred from exiting the station away from the intersection through the use of landscaping. In practice, however, some pedestrians enter or leave the platform by walking around the end of the bus shelter and through the plantings.

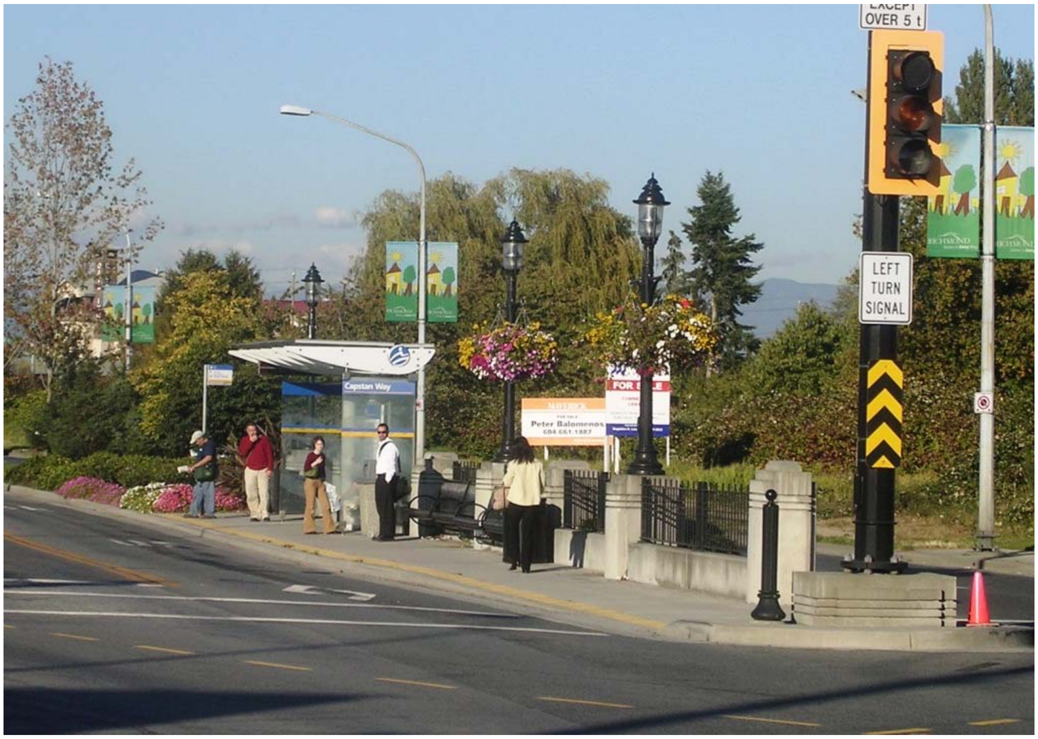


Figure G-4: Decorative Fencing and Landscaping at a Station Stop

The City of Richmond decided to use this type of decorative fencing and dense landscaping because it was more aesthetically pleasing than continuous rail. Originally, the landscaping included some concrete bands to separate the planting beds. These bands were used by pedestrians as mini-walkways for midblock crossings. The majority of these bands have been removed to deter midblock crossings.

OPERATIONAL ASPECTS

All of the intersections of the busway are signal controlled. There are no stop-controlled, uncontrolled, or mid-block pedestrian crossings of the busway.

Signals

Signal Hardware and Configuration

The busway employs standard traffic signals for both general purpose traffic and for buses on the busway. According to the Mr. Wei in the City of Richmond, light rail signals were not used because the City wanted to use standard traffic signals and because light rail signals are currently not allowed in the British Columbia Motor Vehicle Act. Additionally, Mr. Wei notes that a bus is a vehicle, not a train; vehicle signals are appropriate.

The busway signals have a black signal head mounted with a black backplate. All other signals at the intersection are mounted with a yellow backplate. Black backplates are not used at any other signals in Richmond. An example of the signal configuration and backplates is presented in Figure G-5. The purpose of using backplates for the busway intersections is to reduce their visibility to general purpose traffic and to differentiate the signals from the other traffic signals. There are always two signal heads for the busway movement. Signal heads are a size, 12”, along the corridor.

As illustrated in Figure G-5 the left turn signal indication is displayed on a separate signal head from the right and through movements. In the figure, the signals for the left turning movement are displaying a red ball. At most intersections, there are three signals for the left turning movement. In addition to the two pictured in the figure, there is also a side-mounted signal on the left-side opposite corner. The left turn signal is identified with a sign. The driver views this signal during their turn.

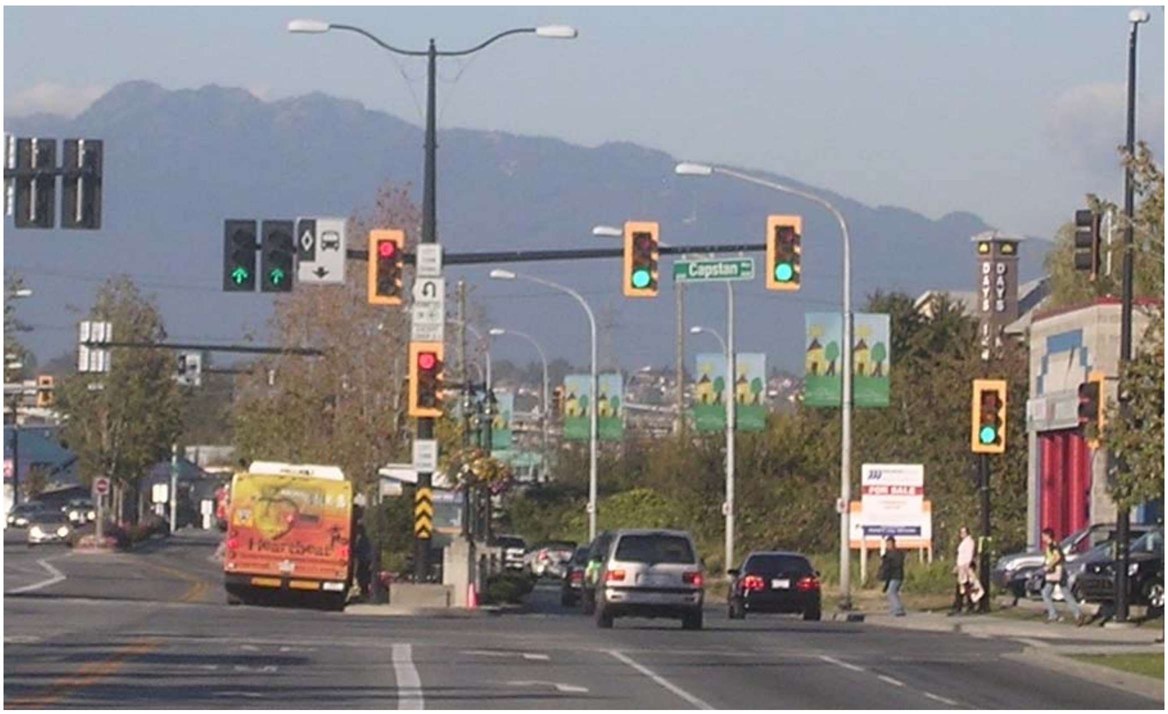


Figure G-5: Traffic Signal Display and Backplates along Busway in Richmond, BC

When the signals were first installed, there was a large problem with parallel traffic being able to see the busway signals. Louvers were installed to shield the view of the busway signals. They were also installed on the left turn signals. The louvers effectively limit visibility to the immediate lane. After the louvers were installed, maintenance received many calls that the signals were out. However, this was because the louvers were so carefully aimed that only vehicles in the lane could see the indication.

Because the signals are so precisely aimed, a solid mast arm mount is needed. If the signals were not rigidly placed, the signal indication would be difficult to see if the signal swayed during wind.

A separate department is responsible for the signing and pavement markings. However, all signing and markings related to these intersections are reviewed by the signal operations unit before installation.

Signal Indications

The busway signals display green through arrows for through and standard yellow and red balls. The left turn signals use a green arrow for lefts and standard yellow and red balls. The signals for the through and right turn movements display standard green, yellow, and red balls.

Signal Operations

With the exception of the entry and exit points from the busway, all of the signalized intersections employ the same type of signal timing. This can be briefly described as follows:

- Left turns are allowed at all of the signalized intersections. Left turning vehicles execute their turn in a protected, leading left turn phase. This phase is before the busway phase. The signal display is a green left turn arrow.
- The busway through phase is concurrent with the general purpose through phase. The bus signals display green through arrows. The busway phase is displayed regardless of whether a bus is approaching.
- The buses do not make any turns at the busway intersections.
- At some of the intersections, U-turns are allowed with the left-turning vehicles or in place of left-turning vehicles at T-intersections.
- The minor streets can operate in split phasing (i.e., westbound and eastbound traffic have separate phases) if necessary.
- Although rarely used, the major streets can also operate with split phasing.

Table G-2 displays the signal timing for an example intersection along the corridor. A ten-phase signal is used at this intersection. During peak periods, most signals operate with a 120-second cycle length.

Table G-2: Signal Timings at No. 3 Road and Alderbridge Way Intersection

Phase	Movement	Minimum Green	Yellow	All Red
1	Southbound Left	3	3	1
2	Northbound Left and Through	1	0	0
3	Westbound Left	5	3	2
4	Eastbound	8	4.5	2
5	Northbound Left	3	3	1
6	Southbound Left and Through	1	0	0
7	Eastbound Left	5	3	2
8	Westbound	8	4.5	2
9	Northbound, Southbound, and Busway	15	4	1.5
12	Bus Only Phase	3	3	0

Although the signal has ten phases, it usually operates with the following phasing sequence:

- Phase 1 and Phase 5 (Southbound and Northbound Lefts)
- Phase 9 (Northbound and Southbound throughs and rights concurrent with both the northbound and southbound busway movements)
- Phase 4 (Eastbound movements)
- Phase 8 (Westbound movements)

The traffic signal operations staff in Richmond were asked why leading left turns were used as opposed to lagging left turns. Leading left turns are the standard practice in Canada. The agency staff did not want to violate driver expectancy by using lagging left turns. They wanted to be consistent in the corridor. The agency staff also noted that there could be some safety concerns with lagging left turns, particularly if a through vehicle ran the traffic signal at the end of the through interval and at the start of the left turn interval.

Signal Failure Mode

In the event of a power failure to the intersections, the intersections operate as stop controlled intersections. The buses, like the other vehicles, have to stop at the intersections until right of way can be ascertained. This can cause complications with vehicles turning left at the intersection. The agency staff indicated that a power back-up system such as a UPS system that allowed the signals to flash red would be helpful.

Signal Priority

Transit Signal Priority

The corridor is equipped with a transit signal priority (TSP) system. The system has the ability to extend a green interval for the busway or provide early red truncation for the side street traffic. With the exception of the signals at the entry and exit points of the system, the TSP system does not have the ability to preempt an entire phase at an intersection.

The buses are equipped with a global positioning system (GPS) Automatic Vehicle Location (AVL) technology. The AVL system tracks the location of the buses. When vehicles become delayed past a determined threshold, an automatic priority request is sent to the City of Richmond signal controls by means of an on-board transponder. Upon receipt of the request, priority is provided through green interval extension or red truncation of the side street. This priority is ended when the bus clears the intersection.

The signal priority system is based on adherence to schedule instead of bus headway. That is, the requests for priority are sent when the transit vehicles are behind their pre-determined schedule. Signal priority is granted conditional when vehicles are at least two minutes behind schedule. This is based on a number of timing “check-in” points along the entire route. There is some concern with the Richmond signal staff and the bus operators that the location of the check in stations does not provide for optimal busway priority along the corridor. For example, busways heading northbound cannot benefit from the TSP system along the busway because of the placement of the check-in timing points. The buses start their schedule clock a few blocks south of the southern end of the busway after leaving the layover station. The next timing check-in station is not until after they have departed the busway. Therefore, even if they are running behind their schedule while in the busway, the system does not know this until the bus passes the next timing station, which is beyond the busway.

There is some uncertainty about the time threshold for schedule adherence. TransLink staff reported that the time threshold was two minutes behind schedule. The City of Richmond staff noted that it was closer to four to five minutes behind schedule.

The bus drivers noted that they do not think the TSP system always works. To increase confidence in the system, there is a TSP test check-in at the bus garage. As buses leave the bus garage, they drive by the test check-in point. A signal flashes as they pass if their onboard TSP equipment is functioning.

The City of Richmond traffic signal staff indicated that they would prefer an advance pavement loop system that allowed for direct priority or pre-emption instead of an on-board schedule adherence system. With the current system, there is some disconnect between how the requests come in and how the traffic signal timing model works. They recommended that agencies who are thinking of employing a bus priority system should make sure all agencies are involved in the planning stages of the system to ensure that the selected priority system is the most compatible with the signal controllers.

The reported average green extension and red truncation in Richmond are shown in Table G-3 as reported in a study by the TransLink. The frequency of TSP comprises 15 to 25 percent of the number of cycles throughout the day.

Table G-3: Average Green Extension and Red Truncation in Richmond

Signal Phase	AM (seconds)	Midday (seconds)	PM (seconds)
Average Red Truncation	7.2	7.9	8.1
Average Green Extension	6.5	6.4	4.6

(Source: Based on data from the 98 B-Line Bus Rapid Transit Evaluation Study. IBI Group, TransLink, Vancouver. September 2003.)

Emergency Vehicles

Emergency vehicles are permitted to use the busway when responding to an emergency. The emergency vehicle system in Richmond is equipped with a central route system that preempts signals for the vehicles. Because the preemption system defines the emergency vehicles entire route instead of just preempting signals on the vehicles approach, there is enough advance information to safely clear pedestrians from the intersections. During the preemption, the pedestrian WALK interval can be truncated but the pedestrian clearance interval (Flashing DON'T WALK) is not altered. This allows pedestrians to clear the intersection prior to the emergency vehicle's approach.

Vehicle Signs and Pavement Markings

Guidance for Left Turning Motorists

Pavement markings are used to guide left turning motorists through the intersection. These pavement markings are often referred to as "puppy tracks". These pavement markings are placed for left turning motorists from the side streets so that the motorists do not accidentally turn into the busway and for left turning vehicles from the roadway parallel to the busway to guide left turning motorists past the busway. The city of Richmond experiences virtually no snowfall during the winter that would obstruct these pavement markings.

Guidance around Busway Island

At each busway intersection, a roadside delineation sign is used to delineate the busway island. This sign and placement is depicted in Figure G-6. This sign could potentially help deter unauthorized entry, however its primary purpose is to keep vehicles from hitting the median or the post.

Figure G-6: Example of Roadside Delineator Sign on Busway Island

Signs to Deter Unauthorized Entry

The busway is marked with two types of signs to deter unauthorized entry. The first is a graphical DO NOT ENTER sign. The second is a transit lane sign.

Colored Pavement

The busway does not employ any type of colored pavement. However, all interviewed staff noted that colored pavement would be a good addition to the system. TransLink is currently testing a short section of colored pavement on a bus only lane leading into the airport bus stop. The section is colored red. Agency staff were asked what color of asphalt they would use if they implemented in on their busway. Staff responded that red or blue would be used but they would need to do some more research to determine the most appropriate color.

Pedestrians and Non-Motorized Users

All signalized intersections are equipped with pedestrian crossings on one or more of the approaches. Standard pedestrian signals are used to assist pedestrians in their crossings. The City of Richmond staff noted that having pedestrian signals at every intersection is important to control the crossings.

Each intersection is assisted with a pedestrian push button to activate the pedestrian interval. A graphic sign is displayed above the push button to communicate to the pedestrians to push the buttons. An example of a pedestrian push button and the accompanying sign is presented in Figure G-7.

Figure G-7: Pedestrian Push Button and Sign

Some intersections also have pedestrian push buttons in the medians. Intersections are only equipped with these pedestrian push buttons if there is a bus stop at the intersection that leads to the median. Otherwise, there is no median actuation for pedestrians. However, the pedestrian signal timings are such that the interval is long enough for a pedestrian to start at one side and cross to the other with the available time. Although the medians are wide enough to provide refuge, they are not intended for that purpose.

The intersections are also equipped with some measures for pedestrians with visual impairments. A number of the pedestrian crossings are equipped with accessible pedestrian signals that provide an auditory indication for the pedestrian intervals. Additionally, all of the busway stations are equipped with tactile warning strips on the edge of the landing area. This tactile warning is a set of raised domes that could be detected by a pedestrian with visual impairments using a cane.

Unauthorized Entry

Signs and pavement markings are the primary methods used to deter unauthorized entry into the busway for motor vehicles. There are no measures directed at pedestrians or bicycles to deter unauthorized entry. There is no special enforcement of unauthorized entry to the busway. Cameras are not employed on the system to monitor entry. The agency staff interviewed at the City of Richmond and with TransLink did not consider unauthorized entry at the intersections to be a problem.

The project team asked the participating agencies if gating was considered as an option for controlling access in and out of the busway at intersections. All interviewed participants indicated that gates are not necessary. The City of Richmond representatives noted that the buses are part of a vehicle in the roadway.

Interaction with Side Street Traffic

At some busway intersection locations, vehicles are legally allowed to make a U-turn from on the mainline from the left turn lane. This concession was necessary to alleviate concerns expressed by the local businesses that the busway would limit access along No. 3 Road. A sign located near the left turn signal indicates that the U-turn is permitted on the green left turn arrow indication. Figure G-8 illustrates this sign and it's placement on the traffic signal pole between left turn signals. As noted in a supplementary plaque accompanying the sign, U-turns are not permitted for vehicles over five tons. In Canada, U-turns are not allowed unless posted.

Figure G-8: Placement of Sign Permitting U-Turn

When the U-turns were first implemented, there was some concern that there could be conflicts between the vehicles making their U-turn on the main road and vehicles making right turns on red from the side street. Signs prohibiting right turn on red were installed on the side street approaches at the intersections where these U-turns were allowed. However, these signs were recently removed by the City of Richmond. The City staff noted that the signs are not necessary; Vehicles on the side street approach are required to yield. Allowing the right turns on red was necessary to ensure that all of the side street traffic can make it through the intersection during their signal cycle. Right turns on red help to alleviate this queue discharge.

SAFETY

As discussed in a previous section, before the busway was constructed, the roadway corridor was a five-lane cross-section with two through lanes in each direction and a center two-way left turn lane. As part of the construction process, the lanes were narrowed to accommodate the busway. The roadway essentially became a four-lane divided roadway. The narrow lanes reduced vehicle speeds. The new divided cross section and lower vehicle speeds reduced crashes along the corridor.

After the busway initially opened, many crashes at the intersections were caused by motorists confusing the traffic signals with their own. Drivers waiting to turn left at the intersection would mistake the bus signal as their own and turn left into the path of approaching buses, either from the opposite direction or from the same direction. This problem was corrected when the city installed louvers that limit the view of the signal to the immediate lane.

A pedestrian was also struck not long after the busway opened. The pedestrian was crossing at the Yaohan Center intersection. This is a busy shopping center. The pedestrian was crossing the busway from West to East. The pedestrian waited for one bus to pass and then stepped into the busway. The pedestrian was not aware that another bus was coming from the opposite direction.

In the three-year period from 1997 through 1999 before the busway was constructed, there were 1,065 reported incidents at the ten intersections listed in Table G-1. In the three-year period from 2002 through 2004 after the busway was constructed and open for service, there were 958 incidents reported at the same ten intersections. This is a reduction of 10%. During the same periods, incidents resulting in an injury were reduced 32% from 359 to 244.

Based on a review of the individual crashes at intersections involving buses, vehicles swerving into the bus lanes at the intersections and vehicles turning left into or in front of buses at intersections are the leading cause of incidents involving buses. There were also a few reported incidents of vehicles turning left from the cross streets into the busway.

PERSPECTIVES OF BUSWAY DRIVERS

The research team interviewed a number of drivers at the layover stop at the end of the busway. The bus drivers were asked for their input on the safe operation of the busway.

Unauthorized Entry

Many bus drivers indicated that unauthorized entry is a regular occurrence on the busway. Private vehicles enter the busway accidentally, often while turning left at one of the busway intersections from the cross street.

Pedestrians

The bus drivers noted that midblock crossings across the busway and crossing against the signal at the busway intersections are a problem. However, they also noted that pedestrian behavior is no better or worse along the busway than along other routes.

Signal Operations

Many of the bus drivers expressed frustration with the signal timings. One noted that the buses should be allowed to go before the left turning motorists. Several noted that they do not receive signal priority when they are behind schedule.

PUBLIC INFORMATION CAMPAIGN

When the 98 B-Line was first launched, an implementation brochure was developed and distributed. The brochure provided information about the whole line, not just the busway portion. A portion of the brochure was dedicated to the busway and noted the length of the busway, the project cost, the separation employed, and how the movements would be controlled.

A notable public information campaign launched that relates directly to the busway intersections provided information on the allowance for U-turns at some of the busway intersections. A color three-fold brochure was developed that explained the U-turns. Over 15,000 copies of the brochure were distributed at community centers, shopping centers, libraries, and motor vehicle departments. The brochure was also disseminated in the newspaper and in driving classes. In addition to English, a Chinese version of the brochure was also developed and distributed.

APPENDIX H
FUNCTIONAL ANALYSES

INTRODUCTION

In order to provide a safe environment for all users of a busway intersection, the needs of those users must be understood. One method of identifying the needs of users is to conduct a functional analysis for the crossings. A functional analysis, also called a task analysis, identifies the information requirements of each user, the source of that information, and the actions that are required of the user. From this information, inappropriate behaviors/actions can be anticipated and potential countermeasures can be identified to deter the inappropriate actions.

This method is based on an IDA model (Information – Decision – Action). It is a simplistic human behavior analysis procedure used in the human factors arena to identify systematically the needs of a user in response to a given situation. This model takes on different elements for the specific task at hand. The primary application of this model in transportation is to identify what information (e.g., signs, signals, pavement markings) a user needs in order to make correct decisions to maneuver a transportation scenario (such as a busway crossing) safely. This approach is used in a number of similar applications including *NCHRP Report 470: Traffic-Control Devices for Passive Railroad-Highway Grade Crossing* (4) and in *NCHRP Report 130: Roadway Delineation Systems* (5).

The following sections present functional analyses for four intersection designs: a median busway intersection, a side-aligned busway intersection, an independent busway intersection, and a midblock pedestrian crossing. The crossings are signalized in all four scenarios.

SIGNALIZED MEDIAN BUSWAY INTERSECTION

Table H-1 presents the functional analysis for a signalized, median busway intersection. It assumes that the busway runs north-south in the median of an arterial roadway. There is a northbound station on the far-side of the intersection. There are many users at this type of intersection including:

- Northbound and southbound buses,
- Northbound and southbound through vehicles on the arterial,
- Northbound and southbound vehicles turning left from the arterial across the busway,
- Northbound and southbound vehicles turning right from the arterial;
- Eastbound and westbound through vehicles on the cross street;
- Eastbound and westbound vehicles turning left from the crossing street;
- Eastbound and westbound vehicles turning right from the cross street;
- Pedestrians and other non-motorized users crossing the arterial and the busway;
- Pedestrians and other non-motorized users crossing the cross street; and
- Pedestrians leaving the busway platform.

The functional analysis of all of these users is not necessary; to many of them, the busway intersection is the same as at a traditional intersection. For example, a pedestrian crossing the east leg of the intersection across the cross-street is not influenced by the presence of the busway in the median.

Table H-1 presents the functional analysis for five key users whose needs at the intersection are affected by the busway:

- A pedestrian heading west, crossing mainline and median busway;
- A pedestrian leaving median station on north side of road and crossing at intersection heading west;
- A mainline motorist traveling turning left at intersection;
- A side-street motorist turning left at intersection; and
- A bus operator for bus traveling through intersection to far-side station.

Table H-1: Functional Analysis for a Signalized Median Busway Intersection

User	Information or Process Requirements	Source of Information	Actions that are Required	Anticipated Inappropriate Behaviors or Actions
User: A pedestrian heading west, crossing mainline and median busway				
	Detect presence of intersection and need to cross	Visual cues include crosswalk markings, curb ramps, pedestrian signal, and street sign Non-visual cues include tactile warnings and audible signals	Stop at intersection	Proceed into intersection when they do not have the right-of-way
	Determine appropriate location to cross	Crosswalk markings Curb ramps Tactile curb ramps	Position themselves at curb	Position themselves at another location
	When to cross northbound general purpose traffic	Pedestrian signal indication View of northbound vehicles or sound "wall" of side-street vehicles	View pedestrian signal indication or listen for indication (if available) Scan for approaching vehicles or turning vehicles	Cross during vehicle right-of-way
	Determine when to cross busway	Pedestrian signal indication View of oncoming buses, both directions or sound of approaching buses	View pedestrian signal indication or listen for indication (if available) Scan for approaching buses, both directions	Cross during busway right-of-way
	Determine when to cross southbound traffic	Pedestrian signal indication View of oncoming southbound vehicles and turning vehicles from side street or sound "wall" of side-street vehicles	View ped signal indication or listen for indication (if available) Scan for approaching vehicles, including side street turning vehicles	Cross during mainline right-of-way Fail to see turning vehicle that is not yielding to pedestrian right of way

Table H-1: Functional Analysis for a Signalized Median Busway Intersection (cont'd)

User	Information or Process Requirements	Source of Information	Actions that are Required	Anticipated Inappropriate Behaviors or Actions
User: A pedestrian leaving median station on north side of road and crossing at intersection heading west				
	Determine appropriate place to cross	Visual cues include crosswalk markings, curb ramps, pedestrian signal, and street sign Non-visual cues include tactile warnings and audible signals	Position themselves at curb	Position themselves at another location
	Determine when to cross busway lanes	Pedestrian signal indication View of buses or sound of approaching buses	View pedestrian signal indication or listen for indication (if available) Scan for approaching buses, including opposite direction bus	Cross during bus right-of-way
	Determine when to cross general purpose lanes	Pedestrian signal indication View of northbound vehicles or sound "wall" of side-street traffic	View pedestrian signal indication or listen for indication (if available) Scan for approaching vehicles or turning vehicles	Cross during vehicle right-of-way Fail to see turning vehicle who is not yielding to pedestrian right of way

Table H-1: Functional Analysis for a Signalized Median Busway Intersection (cont'd)

User	Information or Process Requirements	Source of Information	Actions that are Required	Anticipated Inappropriate Behaviors or Actions
User: Mainline motorist traveling turning left at intersection				
	Determine left turn is allowed	Signs and pavement markings	View available traffic control devices and position in left turn lane	Failure to identify prohibition if present Position for left turn in wrong lane or past stop bar
	Determine when to turn left	Left turn signal indication	View signal and recognize appropriate indication Ensure that no other users such as pedestrians are in the left turn path	Observe traffic control device for another movement such as the busway Signal violation Entry into intersection when other users are still in the intersection
	Appropriate path for left turn	Previous experiences at this intersection or others Guidance pavement markings through intersection	Turn left into the appropriate receiving lane	Turn into wrong receiving lane

Table H-1: Functional Analysis for a Signalized Median Busway Intersection (cont'd)

User	Information or Process Requirements	Source of Information	Actions that are Required	Anticipated Inappropriate Behaviors or Actions
User: Side-street motorist turning left at intersection				
	Determine left turn is allowed	Signs and pavement markings	Visual scan for information and recognition of sign or pavement marking meaning	Failure to identify prohibition if present
	Determine when to turn left	Left turn signal indication	View signal and recognize appropriate indication Ensure that no other users such as pedestrians are in the left turn path	Signal violation or entry into intersection when other users are still in the intersection
	Appropriate path for left turn	Previous experiences at this intersection or others Guidance pavement markings through intersection Traffic control devices prohibiting entry to busway	Turn left into the appropriate receiving lane	Turn into wrong receiving lane Turn into busway

Table H-1: Functional Analysis for a Signalized Median Busway Intersection (cont'd)

User	Information or Process Requirements	Source of Information	Actions that are Required	Anticipated Inappropriate Behaviors or Actions
User: Bus operator for bus traveling through intersection to far-side station				
	Detect presence of intersection	Previous experience including training Traffic control devices and other visual cues	Scan for traffic control devices Scan for other users in intersection such as pedestrians or vehicle queues	Proceed into intersection without traffic control Fail to yield to users already in intersection Observe far-side pedestrians and fail to see other pedestrians
	Determine if bus has right-of-way	Traffic control devices View of intersections and road users	View signal and recognize appropriate indication Scan intersection for other users, particularly pedestrians who may enter path	Signal violation Entry into intersection when other users are still in the intersection or may enter the intersection
	Proceed through intersection to far side station	Travel lanes and previous experience View of far-side station	Ensure that the station ahead has a position for bus Continue to scan for pedestrians and other users	Block intersection because station is occupied Entry into intersection when other users are still in the intersection or may enter the intersection Enter into station when other users are in station such as pedestrians or other buses

SIGNALIZED, SIDE-ALIGNED BUSWAY INTERSECTION

Table H-2 presents the functional analysis for a closely-spaced, signalized, side-aligned busway intersection. It assumes that the busway runs north-south directly east of an arterial roadway. The separation between the two intersections is not large enough to allow storage between the two intersections. There is a northbound station on the far-side of the intersection.

As with the median busway intersection, there are many users at this type of intersection, however, not all are affected by the busway. Table H-2 presents the functional analysis for five users whose needs at the intersection are affected by the busway

- A pedestrian crossing the side-aligned busway, heading west towards parallel street;
- A bus operator crossing intersection to far-side station;
- Mainline motorist turning left across busway with a protected only phase;
- Mainline motorist turning right across busway; and
- Side-street motorist approaching parallel street westbound, starting east of the busway.

Table H-2: Functional Analysis for a Closely-Spaced, Signalized, Side-Aligned Busway Intersection

User	Information or Process Requirements	Source of Information	Actions that are Required	Anticipated Inappropriate Behaviors or Actions
User: A pedestrian crossing the side-aligned busway, heading west towards parallel street				
	Detect presence of intersection and need to cross	Visual cues include crosswalk markings, curb ramps, pedestrian signal, and busway sign Non-visual cues include tactile warnings and audible signals	Stop at intersection	Proceed into intersection when they do not have the right-of-way
	Determine appropriate location to cross	Crosswalk markings Curb ramps Tactile curb ramps	Position themselves at curb	Position themselves at another location
	When to cross busway lanes	Pedestrian signal indication View of buses, both directions, or sound of approaching buses	View pedestrian signal indication or listen for indication (if available) Scan for approaching buses or listen for sound wall of parallel traffic	Cross during bus right-of-way
	End crossing and start anew before crossing parallel street	Visual cues such as the presence of the median and another pedestrian signal	Stop at median and start crossing sequence again	Proceed into parallel street intersection without the right of way

Table H-2: Functional Analysis for a Closely-Spaced, Signalized, Side-Aligned Busway Intersection (Cont'd)

User	Information or Process Requirements	Source of Information	Actions that are Required	Anticipated Inappropriate Behaviors or Actions
User: Bus operator crossing intersection to far-side station				
	Detect presence of intersection	Previous experience including training Traffic control devices and other visual cues	Scan for traffic control devices Scan for other users in intersection such as pedestrians or vehicle queues	Proceed into intersection without traffic control Fail to yield to users already in intersection Observe far-side pedestrians and fail to see other pedestrians
	Determine if bus has right-of-way	Traffic control devices View of intersections and road users	View signal and recognize appropriate indication Scan intersection for other users, particularly pedestrians who may enter path	Signal violation Entry into intersection when other users are still in the intersection or may enter the intersection
	Proceed through intersection to far side station	Travel lanes and previous experience View of far-side station	Ensure that the station ahead has a position for bus Continue to scan for pedestrians and other users	Block intersection because station is occupied Entry into intersection when other users are still in the intersection or may enter the intersection Enter into station when other users are in station such as pedestrians or other buses

Table H-2: Functional Analysis for a Closely-Spaced, Signalized, Side-Aligned Busway Intersection (Cont'd)

User	Information or Process Requirements	Source of Information	Actions that are Required	Anticipated Inappropriate Behaviors or Actions
User: Mainline motorist turning left across busway with a protected only phase				
	Determine left turn is allowed	Signs and pavement markings	View available traffic control devices and position in left turn lane	Failure to identify prohibition if present Position for left turn in wrong lane or past stop bar
	Determine when to turn left	Left turn signal indication	View signal and recognize appropriate indication Ensure that no other users such as pedestrians are in the left turn path Ensure that there is adequate space for vehicle past the busway (i.e., no vehicle queues in receiving lane)	Observe traffic control device for another movement Signal violation Entry into intersection when other users are still in the intersection
	Appropriate path for left turn	Previous experiences at this intersection or others Guidance pavement markings through intersection	Turn left into the appropriate receiving lane and continue past busway crossing	Turn into wrong receiving lane Stop turn over the busway intersection (in response to a queue)

Table H-2: Functional Analysis for a Closely-Spaced, Signalized, Side-Aligned Busway Intersection (Cont'd)

User	Information or Process Requirements	Source of Information	Actions that are Required	Anticipated Inappropriate Behaviors or Actions
User: Mainline motorist turning right across busway				
	Determine right turn is allowed	Signs and pavement markings	View available traffic control devices and position in right turn lane	Failure to identify prohibition if present Position for right turn in wrong lane or past stop bar
	Determine when to turn right	Right turn signal indication Traffic control devices (namely, signs) prohibiting right turn on red Traffic control devices warning of danger of violating right turn on red prohibition	View signal and recognize appropriate indication View sign and understand meaning Ensure that no other users such as pedestrians are in the right turn path Ensure that there is adequate space for vehicle past the busway (i.e., no vehicle queues in receiving lane)	Right turn prohibition violation Observe traffic control device for another movement Signal violation Entry into intersection when other users are still in the intersection
	Appropriate path for right turn	Previous experiences at this intersection or others	Turn right into the appropriate receiving lane and continue past busway crossing	Turn into wrong receiving lane Stop turn over the busway intersection (in response to a queue)

Table H-2: Functional Analysis for a Closely-Spaced, Signalized, Side-Aligned Busway Intersection (Cont'd)

User	Information or Process Requirements	Source of Information	Actions that are Required	Anticipated Inappropriate Behaviors or Actions
User: Side-street motorist approaching parallel street westbound, east of busway				
	Detect presence of busway intersection in advance of parallel street	Visual cues such as traffic signals, busway street sign, busway crossing warning signs, and pavement markings	Respond appropriately to traffic control device If stop is appropriate, stop prior to busway Be alert for other potential of conflicting users in path	Proceed into intersection without right-of-way Stop vehicle over busway
	Determine when to cross busway	Signal indication	View signal and recognize appropriate indication Ensure that no other users such as pedestrians are in the path	Signal violation or entry into intersection when other users are still in the intersection
	No turns are allowed at busway	Visual cues such as lane assignment signs, pavement markings, turn prohibitive signs	Proceed through intersection when given right-of-way	Turn into busway
	Busway and parallel intersection movement are not staggered	Traffic control devices such as signs and pavement markings Adequate signal timing to complete movement	Proceed past busway intersection and make appropriate movement at parallel intersection	Stopping vehicle over busway Storing vehicle between busway and parallel street

SIGNALIZED, INDEPENDENT BUSWAY INTERSECTION

Table H-3 presents the functional analysis for a signalized, independent busway intersection. It assumes that the busway runs north-south and is intersection by a two-lane cross street. No turns are allowed at the intersection. There is a far-side station for northbound buses at this intersection.

At this intersection, there are only four main users groups since turns are not allowed at the intersection: pedestrians or bicyclists heading north-south across the side street, pedestrians or bicyclists heading east-west across the busway, north-south buses, and east-west motorists.

Table H-3 presents the functional analysis for three users whose needs at the intersection are affected by the busway

- A pedestrian crossing the busway;
- Motorist crossing busway from cross street; and
- Bus operator crossing intersection to far-side station.

Table H-3: Functional Analysis for a Signalized, Independent Busway Intersection

User	Information or Process Requirements	Source of Information	Actions that are Required	Anticipated Inappropriate Behaviors or Actions
User: A pedestrian crossing the busway				
	Detect presence of intersection and need to cross	Visual cues include crosswalk markings, curb ramps, pedestrian signal, and busway sign Non-visual cues include tactile warnings and audible signals	Determine if they have the right-of-way If not, stop and wait	Proceed into intersection when they do not have the right-of-way
	Determine appropriate location to cross	Crosswalk markings Curb ramps Tactile curb ramps	Position themselves at curb	Position themselves at another location
	When to cross busway lanes	Pedestrian signal indication View of buses, both directions, or sound of approaching buses	View pedestrian signal indication or listen for indication (if available) Scan for approaching buses or listen for parallel traffic sound	Cross during bus right-of-way
User: Motorist crossing busway from cross street				
	Detect presence of busway intersection	Visual cues such as traffic signals, stop signs, street sign names, and pavement markings	Respond appropriately to traffic control device Be alert for other potential of conflicting users in path	Violate traffic signal and proceed into intersection without right-of-way
	No turns are allowed at intersection	Visual cues such as lane assignment signs and pavement markings and turn prohibitive signs	Proceed through intersection when given right-of-way	Turn into busway

Table H-3: Functional Analysis for a Signalized, Independent Busway Intersection (cont'd)

User	Information or Process Requirements	Source of Information	Actions that are Required	Anticipated Inappropriate Behaviors or Actions
User: Bus operator crossing intersection to far-side station				
	Detect presence of busway intersection	Previous experience including training Training and visual cues such as traffic signals, stop signs, street sign names, and pavement markings	Scan for traffic control devices Scan for potential of conflicting users in path, particularly pedestrians	Proceed into intersection without traffic control Fail to yield to users already in intersection Observe far-side pedestrians and fail to see other pedestrians
	Determine if bus has right-of-way	Traffic control devices View of intersections and road users	View signal and recognize appropriate indication Scan intersection for other users, particularly pedestrians who may enter path	Signal violation Entry into intersection when other users are still in the intersection or may enter the intersection
	Proceed through intersection to far side station	Travel lanes and previous experience View of far-side station	Ensure that the station ahead has a position for bus Continue to scan for pedestrians and other users	Block intersection because station is occupied Entry into intersection when other users are still in the intersection or may enter the intersection Enter into station when other users are in station (e.g. other buses)

SIGNALIZED, MIDBLOCK PEDESTRIAN CROSSING

Table H-4 presents the functional analysis for a signalized, midblock pedestrian crossing of a busway. It assumes that the busway runs north-south in an independent right-of-way. There is no parallel roadway.

At this intersection, there are only two users groups: bus operators and pedestrians (or other non-motorized users). Table H-4 presents the functional analysis for the two users.

SUMMARY OF FUNCTIONAL ANALYSES

In order to design busway intersections to accommodate all users and anticipate where inappropriate behaviors may be undertaken, those who design and operate busway intersections should understand the needs of the users. The functional analysis identifies areas where users need information at busway intersections. Many needs were identified in these functional analyses. The actual presence of the busway at the intersection is the critical need of all users identified in these functional analyses. Chapter 5, Traffic Control Devices, of *TCRP Report 117* provides suggested devices to provide this information to users.

Table H-4: Functional Analysis for a Signalized, Midblock Pedestrian Crossing

User	Information or Process Requirements	Source of Information	Actions that are Required	Anticipated Inappropriate Behaviors or Actions
Pedestrian or bicyclist crossing busway				
	Locate crossing	Signs or channelizing devices directing ped to midblock crossing Visual cues include crosswalk markings, curb ramps, pedestrian signal, and busway sign	Determine if they have the right-of-way If not, stop and wait	Proceed into intersection during bus phase Cross at uncontrolled midblock location
	Locate actuation method and activate system	Signs or locator tone	Activate system and wait for right-of-way assignment	Fail to activate system Proceed into intersection during bus phase
	When to cross busway lanes	Pedestrian signal indication View of buses, both directions, or sound of approaching buses	View pedestrian signal indication or listen for indication (if available) Scan for approaching buses	Cross during bus right-of-way
User: Bus operator crossing pedestrian crossing				
	Detect presence of pedestrian crossing	Previous experience and training Visual cues such as traffic signals, signs, and pavement markings	Scan for traffic control devices Scan for pedestrians in path	Proceed into intersection without right of way Fail to yield to pedestrians already in intersection
	Determine if bus has right-of-way	Traffic control devices View of crossing	View signal and recognize appropriate indication Scan for pedestrians in path	Signal violation Fail to yield to pedestrians already in intersection

APPENDIX I
DESIGN ELEMENTS

INTRODUCTION

Design elements such as sight distances, corner radii, lane widths, turn lane designs and islands are essential inputs to intersection design. Salient guidelines follow.

SIGHT DISTANCE

Adequate safe stopping sight distance for buses, cars, vans, and trucks should be provided along all sections of a roadway, including intersections. The automobile driver eye height of 3.5 feet above the road surface and an object 0.5 feet above the pavement service are used in making sight distance computations.

The sight distance, *d*, contains two basic components: (1) the perception-reaction distance traveled *before* the brakes are applied and (2) the distance needed for the vehicle to stop. The basic equation is as follows.

$$d = 1.47Vt + \frac{1.075V^2}{a} \qquad \text{[I-1]}$$

Where

t = brake reaction time, 2.5 seconds;

V = design speed, mph; and

a = deceleration rate, 11.0 ft/sec.

Examples of safe stopping sight distances are shown in Table I-1. At 30 mph, a distance of 200 feet is recommended for design, at 70 mph, this distance increases to 730 feet.

Table I-1: Safe Stopping Distance
(Source: Adapted from Ref 1.)

Design Speed (mph)	Safe Stopping Sight Distance (feet)
30	200
40	325
50	475
60	650
70	730

Decision Sight Distance

Decision sight distance is defined as "the distance required for a driver to detect an unexpected or otherwise difficult situation and to make a decision in a safe and reasonable manner." This distance should be provided in advance of busway intersections.

Table I-2 gives values for safe stopping and decision sight distances for speeds ranging from 30 to 70 miles per hour for five avoidance maneuvers. In most situations, decision sight distances are about twice as long as safe stopping sight distances.

Table I-2: Decision Sight Distance (in feet) by Avoidance Maneuver
(Source: Adapted from Ref 1.)

Design Speed (mph)	A	B	C	D	E
30	220	490	450	535	620
40	330	690	600	715	825
50	465	910	750	890	1030
60	610	1150	990	1125	1280
70	780	1410	1105	1275	1445

Avoidance maneuvers B, D and E are the most applicable to busway intersections. The avoidance maneuvers are defined as follows:

- **Maneuver A**—Stop on a rural road with a perception-reaction time of 3.0 seconds
- **Maneuver B**—Stop on an urban road with a perception-reaction time of 9.1 seconds
- **Maneuver C**—Speed, path, or direction change on a rural road with a perception-reaction time of 10.2 to 11.2 seconds
- **Maneuver D**—Speed, path, or direction change on a suburban road with a perception-reaction time of 12.1 to 12.9 seconds
- **Maneuver E**—Speed, path, or direction change on an urban road with a perception-reaction time of 14.0 to 14.5 seconds

Intersection Sight Distance

Specified locations on intersection approach legs and across intersection corners should be clear of obstructions that may block a drivers' view. These clear areas are known as sight triangles. Drivers on the minor road must be able to see approaching motorists or buses from a decision point on the minor road (usually at the stop line), and conversely. The "base" of the sight triangle along the arterial roadway should be *at least* the safe stopping sight distance. From a design prospective, however, it is desirable to provide somewhat greater distances to enable drivers on the arterial road to avoid stopping. This is achieved by providing "intersection sight distance."

Intersection sight distances associated with stop sign control on the minor road are based on the minimum acceptable gap required by the minor road traffic multiplied by the arterial roadway speeds.

Table I-3 presents passenger car sight distances for minor streets left, right, and cross street traffic. The intersection sight distance (base of the sight triangle) along the arterial road is about ten times the design speed. They are longer than stopping sight distances for speeds of 60 mph or less.

Table I-3: Intersection Sight Distances for Stop Controlled Intersections with a Base of Sight Triangle Along Major Roads for Passenger Cars
(Source: Adapted from Ref. 1.)

Design Speed (mph)	Intersection Left Turns	Intersection Right Turns	Cross Minor Road (Design Speed 55 mph)
30	335	290	300
40	445	385	395
50	555	480	495
60	665	575	595
70	775	670	690

HORIZONTAL AND VERTICAL ALIGNMENT

Grades of intersecting roads should be flat as possible. Grades that exceed 3% should be avoidable on intersecting roads because of their possible inputs on driver expectancy. Profile grades on the legs of an intersection should be adjusted on each leg to provide a smooth junction.

Intersecting roads should be tangent and curves should be less than 3 degrees.

CORNER RADII

Corner radius dimensions should provide a reasonable balance between vehicle and pedestrian requirements. Factors influencing radius dimensions include:

- Roadway speeds,
- Types of vehicles making turns,
- Presence or absence of curb parking,
- Width of streets receiving turning vehicles,
- Development type and density, and
- Pedestrian movements.

Cars, buses and trucks should be able to turn from one roadway to another, easily with minimum encroachment on opposing traffic lanes or the receiving street. Since large turning radii increase crossing distances, they should be avoided from a pedestrian perspective.

Along busway intersections where turns are prohibited, tight radii should be used to discourage improper movements. A 10-foot radius is suggested as a maximum.

WHEELCHAIR RAMPS

Wheelchair ramps are required at street intersections, at midblock street crossings, and where pedestrian crossings intersect raised medians and islands. Where a landscaped planting strip separates the sidewalk from the curb, the ramp can be built within this strip.

LANE WIDTHS

General Traffic Lanes

Lane widths should reflect the type of facility, travel speeds, and the presence of buses and trucks. Suggested guidelines for lane widths for general traffic are provided by AASHTO (*1*). Eleven- and twelve-foot lanes are desirable for most types of roads. Narrower lanes are acceptable for turning movements and for through lanes in some situations.

Busway Lanes

Busways on separate rights-of-way should have lanes that are at least 11, preferable 12, feet wide. Shoulders are desirable to accommodate disabled vehicles; the paved area should be at least 3 feet. The opposing directions of travel can be separated by a 2- to 3-foot painted median. The resulting envelope, including shoulders and landscaping or other separation, is about 50 feet. At stations, where passing lanes are provided, the envelope increases to almost 80 feet.

Busways within street medians are normally constrained by the available roadway space between curbs. At least a 22- to 24-foot busway should be provided.

TURNING LANES

It is desirable to provide separate lanes for right or left turns at intersections. The lanes can expedite traffic movements, increase capacity, provide special controls for turning traffic, and improve intersection safety. They can be provided by reducing median widths and/or widening roadways.

Left Turns

The provision of left-turn lanes on the mainline is essential from both safety and capacity at median and side-aligned busway intersections. Shared use of a through lane will significantly reduce capacity, especially where opposing traffic is heavy. One left turn per signal cycle delays about 40% of the through vehicles in the shared lane, two turns per cycle delays 66%.

Accordingly, there has been a constant increase in the number of left-turn lanes along arterial streets and roads. The *Highway Capacity Manual* (*2*) recommends that an exclusive left-turn lane be provided at signalized intersections where fully protected left-turn phasing is provided or where peak-hour left-turn volumes exceed 100 vph. Where left-turn volumes exceed 300 vph, a double left-turn lane should be considered.

The storage requirements for left-turn lanes should be based upon peak 15-min flow rates. The average number of left turns per cycle can then be multiplied by a factor to account for random variations in arrivals. The length of the lane can be estimated, based on the length of cars, the mix of cars, and other vehicles and the arrival rate. This leads to the following equation.

$$L = \frac{VK25(1+p)}{N_c} \qquad \text{[I-2]}$$

Where

L = storage length, in feet;
V = peak 15-min flow rate, expressed in vph;
K = constant to reflect random arrival of vehicles, usually 2;
N_c = number of cycles per hour; and
p = percent of trucks or buses.

Where there are random variations in flow, a factor of 2 is normally applied to the left turns; this implies a failure rate of only 5%. However, where volumes increase toward saturation flow, or where movements are controlled by coordinated traffic signal systems, the random arrival factor can be decreased to 1.5.

The total length includes both the taper and storage length. It should reflect deceleration requirements or the storage distance plus the taper. When the turn lane is provided by narrowing the median area or widening the roadway, a 10:1 taper is suggested. If dual left-turn lanes are provided a 7.5:1 taper is suggested. These tapers allow for additional storage during short surges in traffic volumes.

It may be necessary to transition through traffic lanes around left turn lanes. In such cases, larger transition rates should be used. The transition rate for through traffic should be approximately equal to the operating speed, but never less than one in twenty. Thus, for a 40-mph operating speed and a 12-ft offset, the transition distance would be 12 ft by 40 ft, or 480 ft.

The width of auxiliary left-turn lanes usually ranges from 10 to 12 feet. However, in low-speed urban settings, when the lanes are used only by passenger cars, 9-foot lanes may be used.

Dual left-turn lanes require a minimum median width of 26 to 30 feet assuming 11-foot left-turn lanes. There should be 26 to 30 feet of road space available to receive the left-turning vehicles after they pass through the intersection.

Right Turns

The storage lengths for right-turn lanes, *R*, can be estimated using the following equation.

$$R = \frac{rVK25(1+p)}{N_c N_l} \qquad \text{[I-3]}$$

Where

r = red per cycle;
V = peak 15-min flow rate, expressed in vph;
K = constant to reflect random arrival of vehicles, usually 2;
N_c = number of cycles per hour;
N_l = number of lanes; and

p = percent of trucks or buses.

A random arrival factor, K, of 2 should be used where right-turn-on-red is not permitted. Where right-turn-on-red is allowed, a factor of 1.5 could be used to determine the length of storage for right-turning vehicles. Please note that right-turn-on-red across the busway should not be permitted.

The cycle length chosen to estimate the length of storage lanes should consider the possibility of longer cycle lengths in future years. Where the existing cycle length is less than 90 sec, storage requirements should be based on at least a 90-sec cycle. It is better practice, especially where space is not at a premium, to add 50 to 100 feet to the design initially.

TRAFFIC ISLANDS

Traffic islands are used to separate opposing directions of travel (median islands) or to channelize turns at an intersection (channelizing islands). The islands may be flushed, raised, depressed, or painted. The type should be based on traffic volumes, traffic speeds, crash experience, maintenance needs, and costs.

Median Islands

Raised median islands are used along multi-lane roads to separate opposing directions of travel and manage land access. They improve safety, provide space for left turn lanes, and offer refuge for pedestrians at intersections. For median busway intersections, they also separate the busway lanes from the general purpose traffic at the intersection.

Median width depends upon the available right-of-way, and the functions that the median would perform.

- A 4- to 6-foot median can provide some pedestrian refuge and space for traffic controls.
- A 14- to 18-foot median width can provide space for a protected left turn lane.
- A 60-foot median width can provide ‘U’ Turns and indirect left turns along the roadway.

Wide spacing of median openings is desirable to reduce left turn and median nose conflicts along the roadway. The wide spacing also facilitates traffic signal coordination. The state of Florida for example, permits directional left turns into cross streets at ¼ mile intervals and limits full median openings to ½ mile.

Median opening widths depend upon whether a full or directional median opening is provided and the width of roadways crossing the medians. In most cases, openings should not exceed 80 feet.

The shape of the median opening should reflect the design turning paths, the median width and pedestrian storage requirements. Narrow median openings (such as with left turn lanes) would use a simple circular curve. In other situations, curve linear tapers consisting of parabolic or circular curves will suffice.

The width of median island should serve its intended functions. These may vary from access control or separation of conflict to pedestrian refuge, to shielding of left-turn lanes.

Median islands should begin on tangent alignments and on upgrades or well past crest vertical curves. In some cases it is appropriate to extend a median island to avoid introducing if on a horizontal curve or within an area of limited sight distance.

Channelizing Islands

Channelizing islands are an important part of intersection designs. They have many shapes and types, depending upon specific intersection geometry. They are used to separate travel lanes and separate opposing directions of travel on the approach to an intersection.

Islands that separate right turns from the through travel lanes allow larger turning radii, without expanding the intersection area.

Island design should meet desired objectives. The lanes for turning roadways should be natural and convenient. Islands should be large enough to provide good visibility, and afford pedestrian refuge. Minimum island sizes are presented in Table I-4.

Table I-4: Recommended Island Sizes at Intersections
(Source: Reference 3.)

Location of Intersection	Minimum Size (ft^2)	Desirable Minimum (ft^2)
Urban	50	75
Rural and High Speed Urban / Suburban	75	100

.

Considerations for the use of channelizing islands include the following:

- The proper traffic lanes or turning roadways should appear natural and convenient to their intended users.
- The number of islands should be kept to a practical minimum to avoid confusion.
- Islands should be large enough to be effective. Small islands do not function as channelizing devices and tend to present maintenance problems.
- Islands should not be introduced at locations with restricted sight distance or in the middle of sharp horizontal curves.

Islands should be offset from the main travel lanes to prevent head-on collisions. Approach offsets of 2 to 6 feet are desirable. Corners of islands should be from 1 to 2 feet. On-going research is studying possible revisions in this design to improve pedestrian crossings.

CHANNELIZATION

Channelization of at-grade intersections is frequently used to manage conflicting movements into clearly defined paths of travel through the use of pavement markings and raised islands. Channelization can be used to achieve safe and efficient movement of vehicles and people.

Channelization functions include:

1. Separate conflicting movements;
2. Control angles of conflict;
3. Reduce excessive pavement areas;

4. Control angles of entering and conflicting movements;
5. Favor predominant (major) turning movements;
6. Control speeds;
7. Discourage and eliminate prohibited movements;
8. Protect turning crossing vehicles;
9. Provide space for traffic control devices; and
10. Protect pedestrians and reduce crossing distances between refuges.

REFERENCES

1. *A Policy on Geometric Design of Highways and Streets*, Fifth Edition. American Association of State Highway and Transportation Officials, Washington, D.C., 2004.
2. *Highway Capacity Manual*, Year 2000 Edition, Transportation Research Board, National Research Council, Washington, D.C., 2000.
3. Neuman, T.R. *NCHRP Report 279: Intersection Channelization Design Guide,* Transportation Research Board, National Research Council, Washington, D.C., 1985.